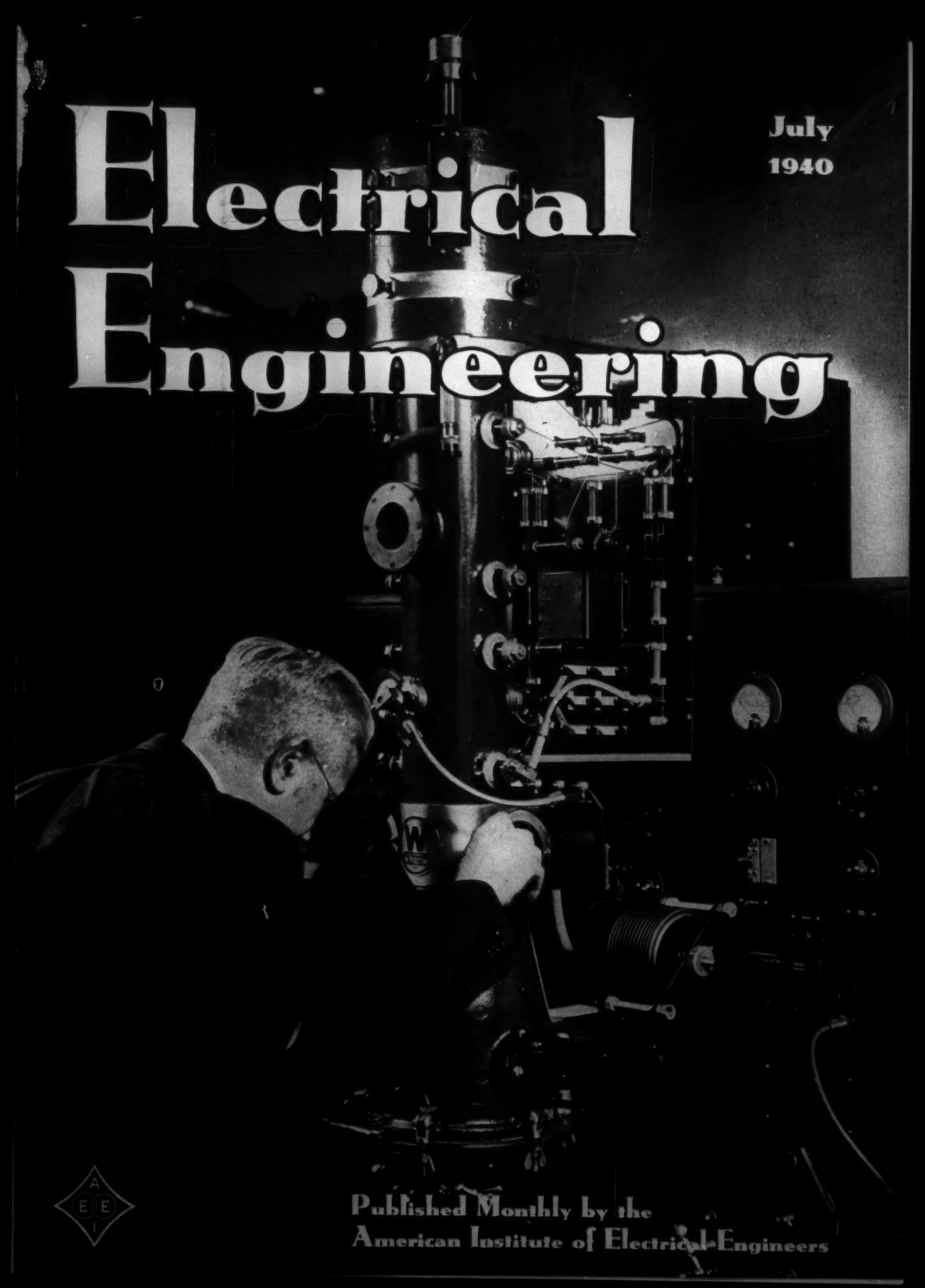
Electrical Engineering

July
1940



Published Monthly by the
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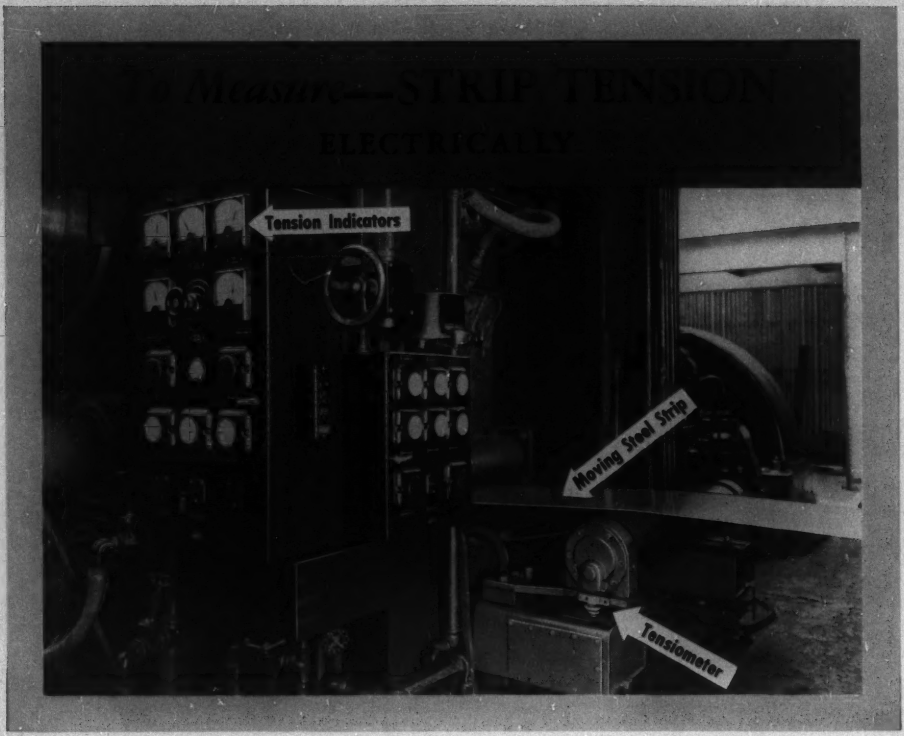

PICTURE in your mind a strip of steel moving 2000 feet per minute—nearly 23 miles an hour—through successive pairs of giant rollers that press it into a smooth thin sheet. Then picture this rapidly moving strip being subjected to varying tensions—pulling, stretching forces in magnitudes up to 150,000 pounds.

In order to produce a uniform strip steel of high quality, and to avoid waste and delay due to strip breakage, it is necessary to control the tension forces in the strip.

But before these forces can be controlled accurately, it is first necessary to measure them.

It was to solve this important measurement problem that G-E engineers developed the tensiometer, an instrument that gives continuous indications of the tension in strip steel during the rolling process. As a result, tension can be controlled, and a better, more uniform product is produced at a lower cost.

Though the measurement job performed by the tensiometer is somewhat special, it is no more remarkable than everyday jobs performed accurately and economically with standard G-E instruments that measure ordinary electrical quantities. There are G-E instruments to measure volts, amperes, watts, power-factor, frequency—in dozens of styles, indicating and recording, and in ratings to fill every need.

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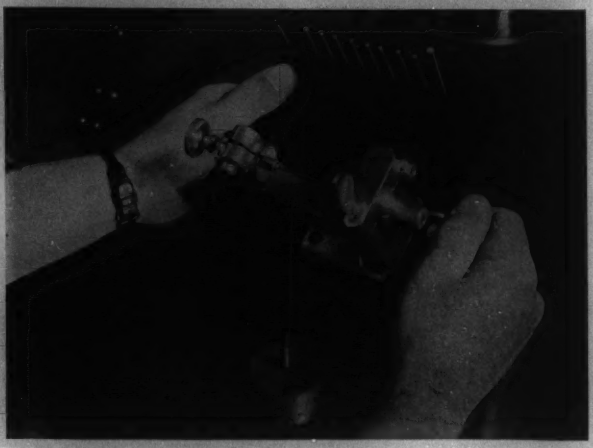


The flexibility tester winds a wire sample under uniform tension on test mandrel

HOW FLEXIBILITY TESTS REVEAL OVERBAKED ENAMEL INSULATION

A flexibility test measures the ability of an enamel film to flex or bend without cracking.

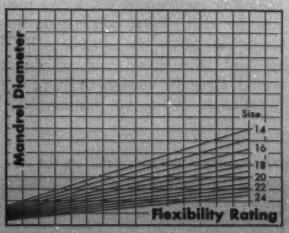
The Belden Flexibility Tester is a standard test instrument, perfected by Belden engineers, for testing the flexibility of an enamel film by winding the conductor around mandrels of progressively smaller sizes.

A sample of wire is wound upon a mandrel and the film is examined under a microscope. If no cracks are visible, a new specimen of the wire is wound around a smaller mandrel and the film is again examined. When cracks appear in the enameled film, the flexibility rating is determined by noting on a standard test curve (see below) the point at which the curve intersects the smallest mandrel size used in the test.

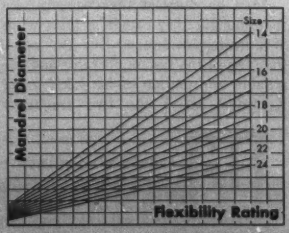
Similar tests can be made on enameled wire after accelerated aging. Another curve gives the flexibility rating for "aged" wire. Overbaked enamel is quickly detected.

All Belden enameled wires must undergo these severe tests. Only balanced insulation, like Beldenamel, will survive them. Specify Belden and be safe.

Flexibility Ratings at Room Temperature



Flexibility Ratings after Accelerated Aging



Flexibility is a vitally important characteristic of enameled wire insulation which must not be sacrificed to get high abrasion resistance . . . . . In Balanced insulation, flexibility and abrasion resistance are carefully matched for the best overall performance of the enameled wire.

WHAT IS BALANCED INSULATION?

Balanced insulation is an enamel insulation which offers a "balanced" combination of essential characteristics.

What are these characteristics?

They are: (1) ability to resist abrasion; (2) flexibility to allow necessary bending in coil winding without cracking; (3) adherence to prevent flaking if the wire is stretched in winding; (4) ability to withstand varnish solvents; (5) good aging quality; and (6) uniformity of insulation thickness.

In Beldenamel, these six essential characteristics are carefully balanced for best performance of the wire in your winding machines and lowest OVERALL winding cost. No single characteristic is sacrificed in order that another characteristic may be high. Therefore, Beldenamel—with its balanced insulation—gives the most satisfactory results in all types of windings.

Do you want to know if you are always getting balanced insulation on the magnet wire which you are using? Just adopt Belden standard test methods . . . and you will know whether some characteristics are too low or too high. Belden standard tests eliminate guesswork in buying wire.

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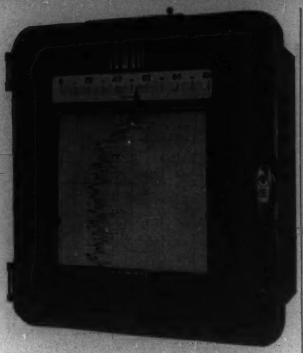
Further data on tests and instruments for rating characteristics of *Balanced* insulation sent on request



Micromax Load Recorder

Load Recorders Pay For Themselves In Emergency

Keep Service On the Line and Save Two Frequency Changers

The story of how an installation of L&N Load Recorders paid for itself is an interesting one even though the companies involved can't be named here. It came to light when one of our men was talking to the system operator at the station where the recorders were installed. Our man was interested in finding out just how the instruments were used in distributing load and was asking questions about everyday operation. Finally he asked how long the operator thought it would take the installation to pay for itself.

"Why, it paid for itself one day soon after it was put into operation," the operator said. He went on to explain as follows:

One of the system's 60-cycle interconnections is paralleled by a 25-cycle line with a 30,000 KW frequency changer at each end. Several days after the recorders had been started, the 60-cycle transmission line went out while carrying full load (several times the rated capacity of the changers). The entire load started flowing out of one 30,000 KW frequency changer, over the 25-cycle line, and back through the other changer.

The operator was on his toes. He saw the load recorder for one changer go off scale on the high side and the recorder for the other changer go off scale on the low side. He realized what was happening and simply pushed a button opening the 25-cycle line.

Men on duty at the changers said they thought they caught a faint whiff of burning insulation. But the quick thinking of the system operator and the reliable information of his L&N Load Recorders saved the two frequency changers from damage and kept the 25-cycle line energized from each end.

Although the investment in load recording instruments was easily justified by the savings effected in this single emergency, its value as a guide to load distribution and scheduling would alone be enough to justify its installation. Write for information.

World's Largest Power Plant Helps Meet New York's Huge Load Swings

770,000-KW Station Now Under L&N Load-Frequency Control

Hudson Ave. Joins Hell Gate To Hold Frequency on Consolidated Edison System

Load swings on Consolidated Edison's 2,300,000 KW system are divided between the Hudson Ave. and Hell Gate Stations in New York City. Three other steam stations usually hold base load, and an inter-connection with the Niagara-Hudson Power Corp. further affects the control of load and frequency.

This entire control is entrusted to L&N equipment, which is arranged to provide various types of regulation, to meet the wide variety of regulating conditions found during normal operation.

For example, under certain conditions this control regulates the frequency and time for the entire interconnection which includes practically the entire state of New York as well as the N. Y. Metropolitan area. At other times the control maintains a scheduled power flow on the ties to the Niagara-Hudson group.

The control can be set so that the New York City stations absorb only the load swings originating in the New York area. Either Hudson Ave. or Hell Gate can be the master frequency-controlling station.

These L&N instruments at Hudson Avenue, in combination with similar equipment at Hell Gate, control frequency and load distribution.

On this system, as on others, this control has shown that it can hold frequency or load interchange far more closely than manual regulation. And it has also shown that stations on the system but not under automatic control hold closer to their assigned base load due to improved system frequency.

This installation is one of over ninety L&N load-frequency control equipments now in use. Together, they have direct control over generators totaling nearly 6 million kilowatts. The interconnections they control total well over 15 million kilowatts.

Controlled frequency and correctly apportioned load are available to every power plant. Write for information.

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The Selenium Rectifier operates with equally high efficiency when wholly immersed in oil—a unique feature which makes it invaluable for service in corrosive atmospheres, such as electroplating.

Other Outstanding Features of I. T. & T. Selenium Rectifiers

The I. T. & T. Selenium Rectifier finds wide, general-purpose application in a variety of forms for the rectification of large or small currents at high or low voltages. It also has many other uses, such as spark quencher, polarizer or electronic valve.

Efficiency: The high efficiency of the Selenium Rectifier over a wide load range assures economical operation, low costs and eliminates maintenance.

Compactness: The high permissible back voltage of the Selenium Rectifier plates holds to a minimum the number required. Also the high current density permits the use of small plates. These features together with simplicity of design make it a comparatively small compact unit.

Overload Capacity: It will withstand short overloads of ten or more times the normal rated current without damage.

Wide Temperature Range: It operates instantly in ambient temperatures of from —40°C. to +75°C. for continuous service — higher for intermittent.

Regulation: Stable output during years of wide use and good regulation with varying load demands.

Electrical Stability: It has no moving parts, it requires no adjustments or replacements, there is nothing to get out of order. It has indefinitely long life.

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Electrical Engineering

Registered U. S. Patent Office

for July 1940—

The Cover: Cathode-ray oscillograph developed for the new high-voltage laboratory of the National Bureau of Standards at Washington, D. C. Photo courtesy of Westinghouse

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VOLUME 59 NUMBER 7

Published Monthly by the

American Institute of Electrical Engineers

(Founded 1884)

F. MALCOLM FARMER, President H. H. HENLINE, National Secretary

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Entered as second class matter at the Post Office, Easton, Pa., April 20, 1932, under the Act of Congress March 3, 1879. Accepted for mailing at special postage rates provided for in Section 1103, Act of October 3, 1917, authorized on August 3, 1918. ¶ Publication Office: 20th & Northampton Streets, Easton, Pa. Editorial and Advertising Offices at the headquarters of the Institute, 33 West 39th Street, New York

¶ Statements and opinions given in articles and papers appearing in "Electrical Engineering" are the expressions of contributors, for which the Institute assumes no responsibility.

¶ Correspondence is invited on all controversial matters.

High Lights • •

Impulse Strength. Cable insulation often has been damaged by lightning, but little information regarding its impulse strength has been available. Some tests on oil-treated paper-insulated cables over the range of insulation thickness from 0.187 to 0.600 inch, including several grades or densities of paper, indicate higher breakdown values for the denser papers, but the average breakdown stress values found were approximately 1,600–1,700 volts per mil (*Transactions pages 389–94*). Other tests with impulse voltages on rubber and varnished-cambric insulation indicate strengths for rubber of from 700 to 1,600 volts per mil, depending upon the compound, and for varnished cambric and oil-impregnated paper about 1,000 and 2,000 volts per mil respectively. These values are about from two to four times the 60-cycle strength of rubber, and three to four times that of cambric and paper (*Transactions pages 394–402*).

The Ionosphere. Were it not for the ionosphere, the electrically conducting envelope surrounding the earth at an altitude of several hundred miles above its surface, radio as we know it today would be nonexistent. Chief agency in producing the ionosphere, which consists of a mixture of electrified and nonelectrified gases, is the intense ultraviolet radiation from the sun which if not exhausted in forming of the ionosphere would probably be intense enough at the earth's surface to be deadly. The lethal short waves of the sun are spent, therefore, not harmlessly merely but usefully, in erecting the barrier to keep the long waves of the wireless pent up within the lower atmosphere where they can be of value (*pages 272–83*).

Electricity in the Navy. Three outstanding electrical accomplishments in the United States Navy in recent years have been: (1) the introduction of electric propulsion on surface ships; (2) the use of alternating current in place of direct current; and (3) the development of Diesel d-c electric drive on submarines, according to a commanding officer in the Navy, who says that "the Navy is keenly aware of the future development of engineering in all phases and is continuously pushing new ideas and developments in order to increase the military effectiveness of the ships" (*pages 267–70*).

Power for Airplanes. The electric-power loads of airplanes are growing rapidly to meet the demands of increases in size, speed, and flying range. Present-day applications require large generators operating at relatively high voltages to assure economic installations. Units are designed to secure minimum weight for a specific flight time, and may be of either of two general systems —a 110-volt 400-cycle three-phase system for large aircraft, or a 24-volt d-c system for lighter types of planes which have small motor loads (*Transactions pages 385–9*).

Fluorescent Lighting. After two years in service, the fluorescent lamp no longer can be considered a lighting novelty; it has proved to be a practical and adaptable light source, unusually efficient in the production of both colored and daylight illumination, without excessive radiant heat. It is thought that this new light source will not supplant all other sources, but instead will supplement them, giving the illuminating engineer a further means of creating the high levels of interior illumination needed for eyesight conservation (*pages 261–6*).

Kilowatt-Hour Measurement. The accuracy with which electric energy is metered is dependent upon the apparent measured value of the kilowatt-hour used. An improved system for maintaining the value of the kilowatt-hour to be used primarily for the calibrating and checking of portable standard watt-hour meters is composed of three precision rotating standards, and is capable of maintaining a high degree of accuracy (*Transactions pages 412–16*).

Mercury Condensation. In mercury-arc tubes, vapor continuously evolved from the mercury-pool cathode is condensed on cooled surfaces; the efficiency of condensation has been found experimentally to be quite low. Nickel surfaces condense the vapor several times as efficiently as steel, and a great improvement in efficiency is obtained by positive-ion bombardment of the condenser (*Transactions pages 381–4*).

Power Preparedness. In a national emergency calling for more power, if the power industry does not supply the power, the Government will, says the head of a middle western power company, who states that the power companies have the engineering ability and financial resources, and a habit and tradition of growth that would enable them to take such an assignment completely in their stride (*pages 270–1*).

Inductive Co-ordination. Electromagnetic induction from a power system may cause disturbances on a nearby communication system, the avoidance of which is a problem of co-ordination. Developments during the past decade have affected somewhat the problem of low-frequency induction resulting from power-system ground faults (*Transactions pages 403–12*).

High-Frequency Engineering. To push forward the understanding of high-frequency theory requires that the engineer possess the analytical tools and the ability to apply the tools to the solution of practical problems; because colleges rarely provide the required training, a postcollege course has been established in industry (*Transactions pages 374–80*).

Directors Report. Included in full in this issue is the annual report of the AIEE board of directors to the Institute membership for the fiscal year ending April 30, 1940. It contains brief reports of the activities of the various committees and the usual financial tabulations (*pages 290–303*).

New AIEE Officers. Among other items of business at the annual meeting of the AIEE held during the summer convention just concluded at Swampscott, Mass., was the announcement of new officers elected for the administrative year beginning August 1, 1940 (*page 289*).

Pacific-Coast Convention. Southern California and the Pacific Southwest offer many attractive possibilities for combined vacation and Pacific-Coast-convention trips; the convention inspection-trips committee has offered assistance in planning vacation schedules (*pages 288–9*).

Traction Motors. The introduction of lightweight high-speed motors to electric transportation has modified the technique of selecting motors for specific applications, which is based fundamentally on the speed-time curve (*Transactions pages 369–74*).

New AIEE Committee. Establishment of a new technical committee on domestic and commercial applications was one of the many actions taken at the May 24 meeting of the AIEE board of directors (*pages 303–04*).

Standardization. A statement of policy concerning AIEE standardization activities has been prepared and approved by the Institute's standards committee and was recently approved by the board of directors (*page 306*).

Coming Soon. Among special articles and technical papers now undergoing preparation for early publication are: an article on television, which surveys its history, discusses operating principles, and endeavors to answer a number of questions frequently asked, by G. R. Town (M'37); a paper on water solution in high-voltage dielectric liquids by F. M. Clark (A'24); a paper describing electric couplings by M. R. Lory, L. A. Kilgore (M'37), and R. A. Baudry; a paper on a harmonic theory of noise in induction motors by Wayne J. Morrill (M'35); a paper on the control of inductive interference to telegraph systems by J. W. Milnor (F'30); a paper on induction-motor characteristics at high slip by Theodore H. Morgan (F'39), William E. Brown (A'39), and Arthur J. Schumer (A'39); a paper discussing lightning protection on distribution systems by R. C. Bergvall (A'24) and Edward Beck (M'35); and a paper describing a transient analysis of symmetrical networks by the method of symmetrical components by Louis A. Pipes (A'37).

Subscriptions—$12 per year to United States, Mexico, Cuba, Porto Rico, Hawaii, Philippine Islands, Central and South America, Haiti, Spain, Spanish Colonies; $13 to Canada; $14 elsewhere. Single copy $1.50. ¶ Address changes must be received by the 15th of the month to be effective with the succeeding issue. Copies undelivered because of incorrect address cannot be replaced without charge. ¶ ELECTRICAL ENGINEERING is indexed annually by the Institute, weekly and monthly by *Engineering Index*, and monthly by *Industrial Arts Index*; abstracted monthly by *Science Abstracts* (London). Copyright 1940 by the American Institute of Electrical Engineers. Printed in the United States of America.

Number of copies this issue 21,800.

Fluorescent Lighting After Two Years

OSCAR P. CLEAVER
ASSOCIATE AIEE

After two years in service, the fluorescent lamp has definitely established itself as a new tool for the illumination engineer that will supplement, but not supplant, other light sources

NEW in theory, design, and appearance, the fluorescent lamp was introduced some two years ago to the public and the illuminating-engineering profession at almost the same instant, giving the latter little time to study and prepare essential data before the former began to insist upon its application to every lighting field. The past two years, therefore, have been a period of catching up—of constant improvement in the lamp and its auxiliary equipment, and of rapid assembling of data on its performance and its limitations as a practical and economical light source.

How well the fluorescent lamp has measured up to the demands made upon it—its steady improvement, its dependability in service, its ability satisfactorily to meet modern lighting requirements—is reviewed in this article to provide a brief record of the unusual progress made in fluorescent lighting in so short a time.

The fluorescent lamp has not changed in theory since its introduction commercially, yet the present lamp is not the same lamp of two years ago. It has increased in life span 150 per cent in this time and its efficiency has been improved phenomenally when judged by standards established by incandescent lamps. The summary in table I of the increases in efficiency indicates the suitability of the adjective "phenomenal" in describing what has occurred since March 1939. Improvements in both life and efficiency are primarily due to better manufacturing technique and to research in phosphors leading to greater purification and better mixing.

Lamp life, however, is materially affected by the frequency of starting, because of the effect on the electrodes of the momentary high starting voltage. If lamps are started once or twice a minute, for example, the life will be greatly shortened. However, if lamps are turned on and permitted to burn continuously, the useful life may well exceed 2,500 hours. These two major improvements—longer life and high efficiency—have had considerable effect upon installation costs and, in a measure, may explain the rapidly increasing number of lighting fields wherein the fluorescent lamp is finding economical as well as logical application.

NEW LAMP SIZES AND COLORS

The introduction of the new 48-inch 40-watt fluorescent lamp with a tube diameter of $1^1/_2$ inches also has given stimulus to new applications. This longer tube requires less investment in sockets and auxiliaries per foot of tube and has a slightly higher efficiency, characteristic of the longer tubes. As yet, the 40-watt lamp is available only in the daylight and "new" white colors.

"New," as applied to the present white color, is entirely justified since experience with the former "warm" white indicated that it was much too pink when seeing and not decoration was the main lighting objective. The "new" white has a color temperature of 3,500 degrees Kelvin, as compared with the 2,800 degrees of the old warm white and 6,500 degrees of the daylight color. A result of this change has been the rapid shift in favor to the new white, which is inherently more efficient than the daylight lamp. Two years' experience with the other colors—red, gold, blue, pink, green, and daylight—has justified continuing them without change. Commercially, these colors have met most application requirements.

Of limited application are other fluorescent lamps that have been developed since the first one made its commercial appearance. Of interest is the 58- by $1^1/_4$-inch fluorescent-coated tube designed to operate on an a-c circuit with a rectifying auxiliary, thereby producing nonstroboscopic light at an efficiency of approximately 50 lumens per watt. Two colors are available in lamps of this type: (1) a blue-white, and (2) a white (called "industrial white") having a color temperature of approximately 8,000 degrees Kelvin. The lamp plus the rectifying auxiliary are rated at 100 watts, and its major field of application is industrial lighting.

Confined to special photographic lighting entirely are the two very small four-watt six-inch and six-watt nine-inch fluorescent lamps designed with oval-shaped tubes and special pin-type bases. Their operating characteristics are similar to those of the standard fluorescent lamps, but they require auxiliaries designed especially for them.

FLUORESCENT-LAMP AUXILIARIES ARE IMPROVED

The earliest auxiliaries really consisted of two parts in a single case: (1) a choke to limit the current to the designed value of the lamp; and (2) an automatic switch which, on starting, first closes the electrode circuit and then abruptly breaks it in order to induce a high voltage across the electrodes for starting the arc discharge.

The design of the choke presented no great problem, but the design of a switch proved to be something more difficult because it must have moving parts, and the limitations imposed on its size were rather drastic. For a time,

OSCAR P. CLEAVER is head of the illumination section of the commercial engineering department, lamp division, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.; he also is chairman of the illumination group of the AIEE New York Section.

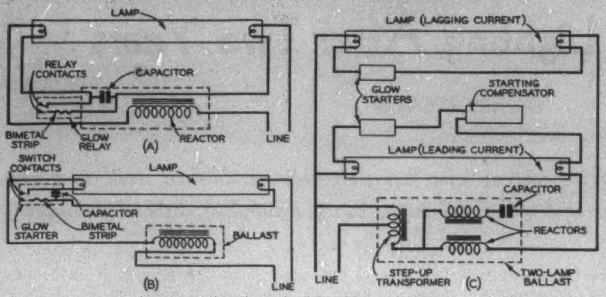

Figure 1. Circuit diagrams showing essential parts of new fluorescent-lamp controls using the glow switch for starting: (A) single-lamp type with glow switch in the end of the auxiliary case; (B) separate-ballast type with glow switch in lamp holder; (C) two-lamp type for high-power-factor operation with glow switch in lamp holder

Figure 2 (below). Lamp holder and glow switch combination; cut-away view of switch container shows component parts

either a thermal switch operating on the principle of the expansion and contraction of a bimetallic strip when heated and cooled, or a magnetic switch similar to the "door bell" type of magnetic contactor, were encased with the choke and permanently sealed. The switch proved to be the element of the auxiliary most likely to become inoperative, and it was soon apparent that the separation of the switch and choke would prove to be a distinct operating advantage. The latest auxiliaries have been designed to give interchangeability and accessibility to the starter, which also has undergone some improvement leading to more positive operation with constant time lag regardless of the frequency of starting.

Table I. Increases in the Efficiency of Fluorescent Lamps Since March 1939

Length of Lamp (Inches)	Diameter of Lamp (Inches)	Color	Per Cent Increase
18	1	Daylight	10
		White (new)	30
		Gold	39
		Blue	15
36	1	Daylight	17
		White (new)	37
		Pink	5
		Blue	20
		Green	7
48	1½	Daylight	28
		White (new)	51

Consider now the changes in the auxiliaries. One design has the new switch inserted in the end of the auxiliary case (figure 1*A*). It therefore can be removed readily, provided the auxiliary itself is readily accessible—which, of course, it rarely ever is since it is likely to be sealed in a fixture or wiring channel. To take care of such situations, the latest improvement consists of casing the choke separately (now called a ballast) and designing the lamp socket to contain the starter switch in such a way that it is directly beneath the end of the lamp; the switch thus is concealed by the lamp, yet is as readily accessible for replacement as the lamp (figure 1*B*).

The new type of starting switch differs from the former type of thermal switch in that the heat required to affect the bimetallic strip now is generated by an electrical glow discharge replacing the former method of heating by an incandescent wire. As a consequence, the new switch is called a glow switch and has the excellent characteristic of being disconnected electrically when not actually in the process of starting the lamp. In practice, the small glass bulb containing the bimetallic strip and gas is enclosed in a cylindrical metal container together with a small capacitor across the switch terminals to reduce radio interference when starting (figure 2).

Along with the separation of choke and starter switch has come another innovation in auxiliary design which was introduced primarily to satisfy demands for higher power factors and less flicker in fluorescent installations without increasing installation costs. These new ballasts, designed for two-lamp operation (figure 1*C*), consist of a choke for one lamp and a choke and a capacitor for the other, both housed in a single case. The inductance and capacitance is such that the power factor of this combination is well over 90 per cent, closely approaching unity in most cases. These new twin ballasts are known commercially as two-lamp ballasts and are available for all sizes of fluorescent lamps of standard design. They, of course, must be operated by glow switches contained in one of the sockets of each lamp. Such a circuit may require a third ballast in series with the lamp operated with the capacitor, as the current for starting this lamp may be insufficient to heat the electrodes properly before the switch functions. The extra inductance in the starting circuit adjusts this condition, and is automatically switched out when the switch operates to start the arc discharge. Fortunately, this ballast is small and relatively inexpensive, and future developments may eliminate it entirely.

The use of two-lamp ballasts results in reduced flicker also, since one lamp is operating at a leading power factor and the other at a lagging power factor, the two being about 115 degrees out of phase. It has been determined that with this type of ballast and lamps close together, the resultant illumination from daylight or white lamps has slightly more flicker than that experienced with an incandescent lamp of 40-watt size on 60-cycle current.

Where odd numbers of lamps or single lamps are used, either high-power-factor single-lamp auxiliaries or special

Table II. Essential Technical Data on Fluorescent Lamps

*Watts (nominal—lamp only)	15	15	20	30	40
Tube	T-8	T-12	T-12	T-8	T-12
Nominal length (inches)	18	18	24	36	48
Approximate lamp amperes	0.30	0.33	0.35	0.33	0.42
Approximate lamp volts	56	48	62	103	108
Maximum over-all length (inches)	17 13/32	17 13/32	23 13/32	35 13/32	47 13/32
Rated average laboratory life (hours)	2,500	2,500	2,500	2,500	2,500
Burning position	Any	Any	Any	Any	Any

* For total watts add wattage loss in auxiliary.

Lamps must be operated with special controls or ballasts designed to furnish the necessary starting voltage and maintain the proper operating current. Standard auxiliaries are available for operation on regular lighting circuits. All lamps listed have medium bipin bases.

capacitors to correct power factors to 80 per cent or above are available in sizes small enough to fit in standard wiring channels. This method, however, increases installation costs, while the two-lamp ballast adds no extra expense when used with the higher-wattage lamps. The over-all wattage loss in the latter auxiliary is about half what it would be if the former-type single auxiliaries for each lamp were used (see table IV). With such corrective equipment readily available, there is no longer any need for not having the advantages of high-power-factor installations in which the full wiring capacity can be utilized effectively.

Operation on direct current has been infrequent and has not been encouraged by lamp manufacturers; however, some notable installations have been made and equipment has been designed for such operation. In such instances, the regular type of ballasts and starter switches must be provided to supply the inductive kick for starting, in addition to a small resistance to control the current to the value required by the lamp. Since as much wattage is dissipated as heat in the resistance as is required for the lamp, no efficiency advantage over incandescent lamps is realized in such installations

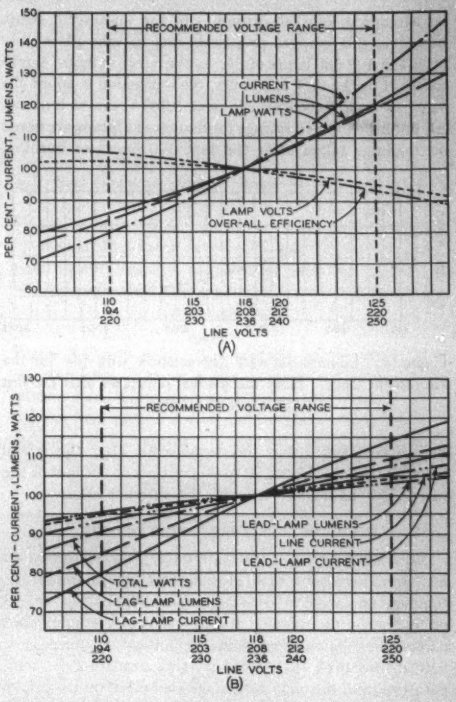

Figure 3. Curves indicating operating characteristics of fluorescent lamps when operated on (A) thermal-type auxiliaries; and (B) two-lamp ballasts. These curves vary slightly from the above when magnetic auxiliaries are used

CHARACTERISTICS OF THE FLUORESCENT LAMP IN OPERATION

The fluorescent lamp cannot be force-tested as can incandescent lamps, and its relatively long normal life has made it impossible to gather essential data on lamp performance as hurriedly as the application engineer might desire. After the experience of two years in operation, however, covering some 2 1/2 million lamps, such essential and authentic data are now available (figures 3*A* and 3*B*). In many ways, the performance of fluorescent lamps differs from that of incandescent lamps, which doubtless will cause some reorientation of traditional thinking on the part of the engineer and the public as well.

For example, it has been customary in the past to assume that lamp life is longer when the supply voltage is less than the rated lamp voltage, and shorter when the opposite occurs. This is true for incandescent lamps, but not for fluorescent lamps. Variations in voltage, up or down from the recommended range of 110 to 125 (220 to 250) volts, apparently shorten lamp life. Lowering the voltage causes the electrodes to operate too cool and the electronic bombardment to become excessive, while raising the voltage increases the dissipation of the active material on the electrodes.

The life of a lamp perhaps is affected more by frequency of starting than by any voltage changes ordinarily encountered in service. Starting causes a momentarily high voltage drop at the electrodes which forces the active material to sputter rapidly, resulting in the gradual formation during life of a dark ring around the end of the lamp at each electrode. This same dark ring may be also a normal indication of the end of useful life, provided it does not occur too rapidly. Whether caused from normal or abnormal circuit conditions, the end results are the same: The voltage necessary for starting is increased and usually exceeds the available supply, causing the lamp to flash momentarily as the starter acts, but the arc never is established again. A new lamp is required.

The fluorescent lamp is somewhat similar to the incandescent lamp, however, with respect to the effect of voltage on light output. Overvoltage or undervoltage burning will raise or lower its output, respectively, about 1 to 2 1/2 per cent (depending on type of choke used) for every 1 per cent voltage variation (figures 3*A* and 3*B*). Old age also takes its toll of lumens as a result of the evaporation of electrode material and of the effect of mercury on the fluorescent coating, both causing gradual darkening of the tube and

its attendant light absorption. In the fluorescent lamp, however, this gradual process begins to take place only after the first 100 hours of life, as the curve in figure 4 indicates. For the first 100 hours, the darkening is about the same as is produced by the next 1,000 hours of burning. All published lumen ratings for fluorescent lamps are based on readings taken after the first 100 hours of burning.

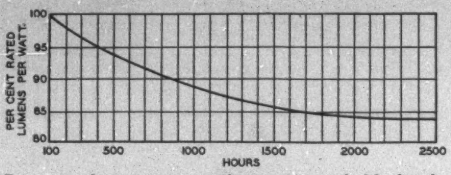

Figure 4. Lumens-per-watt depreciation with life for the fluorescent lamp. Note the gradual reduction after the first 100 hours of burning

Figure 4 indicates that the depreciation after this initial burning period is about 10 to 20 per cent at the end of the rated 2,500 hours, varying with the different colors.

EFFECT OF SURROUNDING TEMPERATURES

No consideration of the surrounding air temperatures has been necessary with incandescent lamps unless the temperatures were so great as to affect the basing cement or to destroy the metallic or glass parts of the lamp; but surrounding temperatures are important in fluorescent lighting because, in a measure, they control tube temperatures and this may have a decided effect on the lumen output of the lamps. The best tube temperature for acceptable performance ranges from about 100 to 120 degrees Fahrenheit; for every one-degree drop below this range there is a one-per-cent decrease in light output. It is well to emphasize the fact that these values apply only to tube temperatures, not to surrounding air-temperature conditions. Contrary to the general belief among the uninformed, the lamp is not a cool one to the touch even though it does deliver less radiant heat per foot-candle than other sources. Hence, if protected from cold air currents by shields or enclosing glass fixtures, it will generate enough heat to make possible its use out-of-doors in cold weather without too great a reduction in light output. This reduction may range from 30 per cent at zero with the lamp enclosed, to as much as 95 per cent in a strong draft with the lamp exposed.

The fluorescent lamp has proved unusually impervious to shock and vibration even in applications where conditions are severe. Its colors are true and can be matched in manufacture; variations in voltage and length of life cause little change in them. In fact, these new lamps have proved serviceable for most normal lighting conditions in modern illuminating engineering.

ECONOMICS OF FLUORESCENT LIGHTING

From the time of its commercial introduction, the new fluorescent lamp has captured the fancy of the man on the street, not alone because of its new appearance and new colors, but because he was told that it was the most efficient source of light available and that it was the nearest approach to "cold" light yet devised in a practical form. High efficiency suggested reduced lighting cost, and cold light greater personal comfort.

Too often ignored, however, was the fact that the cost of energy is only one of many factors that must be considered in determining the cost of lighting. Actually, the cost of equipment, wiring, and lamps often far overbalance any saving in energy costs in fluorescent lighting. After all, the lamp is a low-wattage source, with many required to produce the illumination levels necessary for eyesight conservation. Add to this the relatively high cost of luminaires at present and it is apparent that fluorescent lighting may not always be "low cost" lighting.

The fluorescent lamp need not be promoted only on the basis of low cost, for it has much to offer modern lighting in addition to high efficiency. It offers many new colors at efficiencies no other light source can duplicate; it provides a close approximation of daylight without the necessity of light absorbing screens; it generates "cool" light with only about one-quarter the radiant energy per foot-candle yielded by incandescent lamps; and it is so shaped that it may be readily concealed. These are advantages that any illuminating engineer clearly recognizes; but they are not of such universal importance that all other types of light sources may be discarded.

Many times these desirable characteristics must be purchased at a premium, especially when general illumination with fluorescent lighting is desired, as, for example, when comparing on an equal-foot-candle basis the cost of fluorescent lighting in an office with incandescent lighting at usual energy rates. However, the daylight color of the fluorescent lamp and the "cool" foot-candles it produces may readily justify the extra cost. It is quite probable that this cost differential may not continue to exist in the

Table III. Approximate Light Output of Fluorescent Lamps (Lumens)

Lamp	Daylight	White	Gold	Red	Blue	Pink	Green
15 Watt T-8	495	585	375	45	315	300	900
15 Watt T-12	495	585	375	45	315	300	900
20 Watt T-12	760	900	540	60	460	440	1,300
30 Watt T-8	1,230	1,440	930	120	780	750	2,250
40 Watt T-12	1,800	2,120					

Table IV. Wattage Loss in Various Types of Auxiliaries for Fluorescent Lamps (110–125 Volts)

Type of Auxiliary	Lamp Watts	Watts Loss
High-power-factor two-lamp ballast	60 (two 30-watt lamps)	14½
	80 (two 40-watt lamps)	17½
Ballasts for operation of single lamps	15	5
	20	5
	30	8
	40	13
Single-lamp control units (switch in end)	15	3
	20	4½
Single-lamp control units (thermal switch in case)	15	4½
	20	5
	30	9
	40	14

future, as soon as fixtures emerge from the experimental stage into standard designs. As in all lighting installations, regardless of the source of light, local conditions and the lighting objectives are the big factors to be considered in estimating comparative costs; general statements too often mislead.

APPLICATION TRENDS

The trend in applications of fluorescent lamps up to the present has favored their use for supplementary lighting where levels of 100 foot-candles or more were desirable or where its colors, coolness, and shape were great advantages. The greater majority of the two million or more

Figure 5 (upper left). Decorative fluorescent cove lighting combined with louvered troughs sunk flush with the ceiling provide 35 foot-candles in this large department store. White fluorescent lamps are used for general lighting and for special displays, wall cases, and the silhouette sign

Figure 6 (center). New two-lamp RLM industrial fluorescent fixture on close spacing provides over 45 foot-candles of "daylight" in this drafting room. Two-lamp ballasts are a feature of these fixtures

Figure 7 (lower left). Three 40-watt daylight fluorescent lamps in individual Alzak reflectors form the lighting units in this factory. The general illumination averages 25 foot-candles. Stroboscopic flicker is minimized by operating individual lamps on separate phases of a three-phase circuit

Figure 8 (upper right). Typical of latest fluorescent fixtures for general office lighting are the louvered fixtures in this office. Four 40-watt lamps in each fixture, operating on two-lamp high-power-factor controls, provide approximately 50 foot-candles on the desks

Figure 9 (lower right). Characteristic of the trend toward exposed-lamp fixtures is the fluorescent lighting in this grocery store, where high mounting and supplementary cove lighting from tops of shelves reduce glare. Showcase lighting also is fluorescent. In general, exposed fluorescent lamps are not recommended where eyesight conservation is a factor to be considered in the lighting design

lamps sold have been installed for the following lighting purposes:

Wall cases and showcases.

Show windows (very small windows only).

Decorative merchandise displays.

Indoor directional signs.

Supplementary cove lighting (figure 5).

Art museums (supplementary).

Industrial plants (for supplementary and for production line general illumination, figure 6).

Night clubs, ball rooms, theaters.

Bank cages and offices (supplementary lighting).

Spotting and color discrimination (stores, printing, laundries, dry cleaning).

There is increasing interest, however, in general fluorescent lighting for industrial purposes (figure 7), in offices (figure 8), and in stores (figure 9). This new interest may be more or less attributed to the work of the RLM (Reflector and Lamp Manufacturers) Standards Institute and the Fleur-O-Lier manufacturers group in designing standard types of fixtures that meet the requirements of eyesight conservation as well as electrical requirements. The RLM Standards Institute has long been active in industrial reflector design, but the Fleur-O-Lier group is a result of the fluorescent lighting era. It consists of some 30 manufacturers of fluorescent equipment (fixtures and auxiliaries) who have joined together for the purpose of improving their product. Specifications have been prepared to govern general fixture designs, leading to electrical and eyesight-conservation excellence. A testing laboratory has been engaged to certify fixtures that meet these specifications. It is unwise to predict the extent to which these organizations will influence general acceptance of fluorescent lighting, but at least they will exercise a measure of control on luminaire design.

AUXILIARY HUM AND RADIO INTERFERENCE

Some such control of luminaire design is desirable, for the design and construction of the luminaire not only affects the lighting results, but determines to a great extent the noise or hum "level" of the installation. Noise or hum, of course, originates from the magnetic action in the choke coil elements and is aggravated when these vibrations are transferred to the supporting frame or metallic wiring channel of the fixture. The solution is not always easy, but if all controls are mounted on sponge rubber and attached to the fixture by bolts encased in rubber bushings so that metal will not contact metal, the possibility of excessive hum is greatly reduced if the metal used in the fixture is of good gauge and the fixture tightly assembled. Where absolute quiet is desired, the fluorescent lamp either should not be considered, or all auxiliaries should be located outside the room.

The possibility that the fluorescent lamp may interfere with radio reception also exists, especially if the receiving set is near the lamp. This interference may be attributed to three possible causes: (1) radiation from the lamp which usually may be corrected by moving the receiving set out of the field of the lamp (usually four times the lamp length) or by shielding the antenna in the radiation field and grounding the set; (2) line feedback of radio-frequency energy through the wiring circuit to the radio receiver, which can be stopped or minimized by the regular type of power filter; and (3) radiation from the wires carrying current to the lamp which can be partially eliminated by use of triple filters installed at the lamps. The problem of radio interference and its elimination has received much study, but fortunately little trouble has been experienced in practice.

COLOR CONSIDERATIONS

Other minor installation difficulties have given the engineer some concern. Since the lamp is essentially a low-pressure mercury-vapor discharge type, the spectrum of the mercury discharge is present in addition to the spectrum produced by the fluorescence of the inner coating. As a result, many popular interior colors for walls do not appear as attractive as under incandescent lighting. Some difficulty has been experienced in restaurants from the appearance of food under daylight and white fluorescent lighting. In general, the more vivid wall colors of "cooler" hue are desirable, and the best results in restaurants so far have been obtained with the new white lamp. The color of the light has also resulted in minor photometric difficulties, for the small vest-pocket "light meters", so commonly used today, are not calibrated to measure light of this quality. Two meter manufacturers have made available properly calibrated small light meters which measure illuminations produced by light sources of any color with an accuracy usually associated with such meters.

LOOKING AHEAD

After two years in service, the fluorescent lamp no longer can be considered a lighting novelty; it has proved to be a practical and adaptable light source, unusually efficient in the production of both colored and daylight illumination, without excessive radiant heat. It is generally agreed that the fluorescent lamp will not supplant all other light sources, but instead will supplement them, giving the high illuminating engineer a further means of creating the high illuminations indoors which science indicates are needed for eyesight conservation. Its true value, however, cannot be measured entirely by what has been done with it in the past, but rather it should be judged by what the research engineer hopes to do with it in the future.

In the light of present-day research, its future looks promising, with much to be gained through further investigation of this principle of light generation. New colors, new sizes and shapes, and new efficiencies undoubtedly will come, but in the meantime the illuminating engineer has the important task of educating both himself and the public to utilize the high illuminations now possible indoors, perhaps for the first time, in a practical, comfortable, and economical way. Lighting tables will have to be revised, lighting design approached differently, and lighting equipment revolutionized. This important work is just getting under way.

Electricity in the United States Navy

LOUIS DRELLER

Electricity is used in the Navy as universally as on shore, and plants of 10,000-kw capacity are being installed on capital ships; much greater capacity, of course, is required where electricity is used for propulsion

ELECTRICITY is used on board ship for many purposes; for example, radio, interior communication, cooking, heating, lighting, steering, ventilation, and for training, elevating, and firing the guns. On some ships, as, for example, our electric-drive battleships and airplane carriers, electricity is used to drive the propellers. In short, electricity in the Navy is used as universally as on shore.

Electricity in the Navy may be said to date back to the first installation of an incandescent-lighting plant on the *Trenton* in 1883, about 57 years ago. The plant consisted of an Edison shunt-wound 110-volt generator having a capacity of about 13.2 kw. The generator was driven by a horizontal Armington and Sims single-cylinder steam engine with a steam pressure of about 30 pounds per square inch. This epochal lighting installation consisted of a total of 247 lamps rated approximately at 2,978 candlepower. Contrast this installation with our modern capital ships with electric plants of 10,000 kw, or the 200,000-shaft-horsepower electric-drive installation on the *USS Lexington* and you have some idea of the importance and growth of electricity in the Navy in half a century.

Probably the three outstanding electrical accomplishments in the Navy in recent years have been: (1) the introduction of electric propulsion on surface ships; (2) the use of alternating current in place of direct current; and (3) the development of Diesel d-c electric drive on submarines.

The electric plant on board ship, the same as ashore, consists of generators, distribution boards, power and lighting distribution panels, motors, controllers, transformers, motor generators, cable, and the various types of switchgear and protective equipment. The entire equipment must comprise a flexible, workable, reliable plant.

MAIN GENERATORS

The main generators are driven by either turbines or Diesel engines. The number and capacity of the generators depend in general on the connected load and specifically on the load demands imposed by the various conditions of operation, that is, at anchor, cruising, and during battle. For example, on a cruiser there will generally be four turbine-driven generators, two installed in each engine room. The number of generators varies from two on a destroyer or small ship to eight on a large capital ship. The capacity of the generators must be sufficient to meet the load demands during battle, even though some of the units are disabled or put out of commission by flooding, gunfire, etc. Thus, the primary object is to install generators in sufficient number and capacity to keep the guns and the necessary battle load operative during an engagement, even though the ship has suffered considerable damage.

In large plants, protection from short circuits as well as from gunfire and shock becomes important. Navy designers are therefore most interested in the detailed characteristics of design of generators as, for example, reactance, short-circuit ratio, and voltage regulation, and with their effects on the operation of the entire plant. This subject is receiving special study and consideration by both the Navy and generator builders. On ships in which direct current is used, the generators are generally of the 3-wire types, using 240 volts for power and 120 volts for lighting. On ships where alternating current is used, the generators are normally 450-volt 3-phase 60-cycle, wye-wound machines, normally rated at 0.8 power factor. The power-distribution system operates at 440 volts and the lighting system at 120 volts, obtained by means of air-cooled transformers.

Since the design of a combatant ship is always a compromise between speed, armor, and armament, economy in weight and space becomes of paramount importance in the design of all electrical apparatus installed on board ship. The Navy has been a pioneer in the development of lightweight high-speed generators, both turbine- and Diesel-engine-driven. Reduction in weight has been accomplished through ingenuity of design and the employment of lighter metals and alloys wherever practicable. In addition, all equipment installed on ships must be designed to withstand the corrosive effects of salt air as well as the vibration and shock incident to gunfire and to rolling and pitching. Hence, in addition to heat runs, overspeed, overload, and parallel tests required for commercial generators, Navy machines must pass certain inclination tests. The severity of these tests depends on the class of service for which the units are intended.

The electrical load on board ship varies considerably for the different conditions of operation. This variation in load is caused to some extent by the intermittent demands of the larger motors as, for example, steering-gear motors, training and elevation motors, and air compressors. To take care of these peaks and to insure that the generators are designed with sufficient factor of safety, Navy machines

A paper presented at a meeting of the AIEE Washington (D. C.) Section, February 19, 1940.

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central-station alternators. In the design of the electric plant for shipboard use, the inrush currents due to starting large induction motors must be constantly borne in mind. The magnitude of the inrush current of each circuit is studied and the distribution system arranged so that practically all of the induction motors can be started satisfactorily across the line.

Shunt-wound d-c generators with voltage regulation of about 12 per cent were found best for service operation. In order to obtain an alternator economical in size and weight, the inherent regulation at rated load and power factor is generally poor, approximately 35 to 40 per cent. This regulation is unsuitable for shipboard use. Therefore, the success of the a-c generator depends primarily on the satisfactory operation of the associated voltage-regulation equipment. The regulators developed and installed have proved reliable and satisfactory, and their development is a tribute to the resource, co-operation, and ingenuity of the engineers designing this equipment for the Navy.

This is not the place to attempt to discuss the host of problems and difficulties that were met and ironed out in the development of the a-c plant. However, a few might be mentioned as, for example, speed control of motors, calculations of cable, development of light-weight high-speed, automatically operated Diesel generators that cut in on the line from cold start to supply emergency power after failure of main voltage, balancing of the phases, and short-circuit protection. In general, these problems have been solved, with the result that the changeover from direct to alternating current has been accomplished without trouble and with great benefit to the Service. The problem now is one of refinement, particularly along the lines of decreased weight and space, higher efficiency, and better shock proofness.

The technical bureaus and experimental laboratories of the Navy are reservoirs of engineering data and experience. Each design is based on the accumulated knowledge and design experience of the Navy personnel and of the great number of engineers and technicians in the commercial world engaged in building equipment and ships for the Navy. The ships themselves are the practical laboratories where the results of design and production are tested under service conditions. The "proof of the pudding" is in how the equipment operates on board ship.

The Navy is keenly aware of the future development of engineering in all phases and is continuously pushing new ideas and developments in order to increase the military effectiveness of the ships. It should be fully appreciated, however, that innovations in design and construction must be adequately proved before they can be installed on men-of-war. Equipment installed must be not only thoroughly reliable, but so designed that it can be kept in working order under the most trying conditions of warfare. The major objectives of reliability, ruggedness, ease of upkeep, resistance to shock and vibration, and economy cannot be compromised.

Power Preparedness

The electric-power industry of the United States is said to be capable of meeting any national emergency calling for more power capacity

WILLIAM McCLELLAN
FELLOW AIEE

PREPAREDNESS for war-time power supply or preparedness for war in any other respect, does not mean expectancy of war or desire for war. But just as one takes out a fire-insurance policy as a protection against what he knows may happen but hopes will not, so it is necessary to examine our resources and abilities as though we actually did have to face a war.

Electric power multiplies the effect of manpower and contributes essentially to lower production costs. Power is therefore fundamental to peace-time progress and even more so to war-time effort.

If power companies do not meet the power problems, the Government will do it for them. The Government has appointed a national power policy committee responsible for war power requirements and for peace power requirements as well.

What, then, is the ability of power companies to meet such emergency needs as may arise? First of all is the fact that growth is a tradition in the power industry of the United States. The power companies are accustomed to expansion as a normal and everyday policy. Not only are they accustomed to expand facilities steadily to meet growing demands, but they themselves have encouraged this growth through their sales efforts, one objective of this policy being to achieve greater economy and lower rates.

Moreover, it has been traditional with power companies in the United States to do more than merely meet growth as it occurs. It is their historic policy to keep ahead of demand, to have plenty of power on hand at all times for any need that may arise.

If war should come, it will find the managements of power companies good citizens, just as capable and willing

Abstract of an address delivered at a meeting of the AIEE St. Louis Section, October 18, 1939.

WILLIAM McCLELLAN is president of the Union Electric Company of Missouri, St. Louis; he is past president of AIEE and of American Engineering Council.

to meet Government demands as they proved to be in the last war.

RESPONSIBILITY FOR POWER SUPPLY

That is power companies' responsibility: to provide an ample supply of power in any eventuality. And the time to think about it, the time to prepare—in plan, if not in actual construction—is now. What are the immediate duties of the power companies in this direction?

First, they should see that their present plants are reliable. Many plants are capable of carrying short peaks, but that does not mean they could run 24 hours a day, 365 days a year. When we speak of capacity we must recognize the difference between short-term capacity and ability to carry an equal capacity permanently. A plant capable of taking over a brief peak of 60,000 kw does not represent an actual 60,000 kw of full capacity.

The industry's next concern must be with reserves. When we are considering preparedness we must recognize that maximum reserve is necessary. Perhaps in many cases this means that construction schedules should be advanced. Even in normal operation we now need more reserves than we once did. The former practice of carrying one-unit reserve was made possible because summers, with their relatively low loads, gave opportunities for repairs. Now the load curve is flattening out; we have summer peaks as well as winter peaks, removing opportunities for repairs and bringing about a necessity for two-unit reserves.

EFFICIENT UTILIZATION OF INVESTMENT

The power industry must build ahead. Load growth is gradual, a little at a time; but additions to capacity must be made in large blocks at a time. That means idleness of investment for a time, a situation not, for the moment, altogether satisfactory to the stockholder; but further growth soon begins to absorb the added capacity and thus fulfill the obligations to the stockholders. Likewise, as the normal expected growth begins to utilize the added facilities, the industry avoids having in its rate base an idle investment that would be a burden on its customers.

TRANSMISSION—INTERCONNECTION

One factor that will contribute greatly to our power preparedness is the utilization of every possible opportunity for interconnection and exchange of power between systems. This constitutes, in effect, a sharing of reserves and an assignment of reserves to different localities at different times as needed. This, of course, is a familiar characteristic of the power industry and has contributed greatly to the efficiency of its operations and the economy of its service. In England interconnection has been enforced—through the so-called "grid system"—to the point where, under governmental regulation, permission must be obtained from the government in locating any new power plant. I can cite out of my personal experience the benefits of the exchange of power between Baltimore, Md., and Washington, D. C.,—millions of kilowatt-hours in each direction, profitably to both companies, each of which thereby becomes part of the reserves of the other, providing maximum reserve with minimum investment.

The balance between the necessary provision of reserves and the efficient use of dollar investment—the necessity of earning on stockholders' investment in facilities—must be considered along with all other factors, including the consumers' interests. Suppose, for instance, the Government should decide to build a factory at a given point. Should the necessary resulting power reserve be incorporated in the rate base of the residents of that area? In normal times it is not the power companies' right to burden the consumers of a given locality with a disproportionate rate base, or stockholders with an idle investment, by providing reserves far above the needs of adequate service. But in a war, individual rights and corporate rights become subject to demands of the Government.

MANUFACTURING LIMITATIONS NECESSITATE PLANNING

The necessity for present preparedness grows in part out of the limitation of turbine-manufacturing facilities. There are only three major manufacturers of large turbines in the country and they are engaged in building equipment for naval, military, and industrial purposes, as well as for central stations. This emphasizes the necessity of far-sighted action on the part of the power industry.

On the other hand, there are certain measures that can be taken in the utilization of power that will help in an emergency situation along with efforts to provide additional power. For example, factories now working on 8-hour shifts can change to 16- or even to 24-hour shifts, thus trebling their production with no increase in the kilowatt demand.

When it is a case of building new factories to supply needed materials for war-time use, if the power companies do not already have the necessary reserve of power to serve it, they can certainly supply this as quickly as any factory can be built and put in operation.

There is an even further line of defense if power demands are still greater. That is the rationing of power—for instance, cutting our residence load 10 or 20 per cent and turning this power supply over to industry.

POWER INDUSTRY HAS ABILITY TO MEET NEEDS

We recognize one fundamental fact. In a national emergency calling for more power capacity, if the power companies do not supply the power, the Government will. But we know, too, and so does the nation generally, that power companies are capable of meeting any such emergency. They have the engineering abilities and the financial resources (we may assume that any crippling regulatory restrictions or penalties would be removed) and they have behind them a habit and a tradition of growth which would enable them to take such an assignment completely in their stride.

Our own good citizenship will lead us in the power industry to do our part, not only in such an emergency as may arise, but in anticipating our duty immediately. As good citizens, we will build up to the maximum peace-time reserve; we will be sure that our systems are so interconnected as to give maximum service and maximum reserve.

The Ionosphere

KARL K. DARROW

A physicist "looks at the ionosphere", that electrically conducting envelope surrounding the earth hundreds of miles above its surface which is so essential to radio, and reviews current facts and theories concerning it

SOME YEARS AGO there was a flood of books bearing such titles as "The Doctor Looks at Love", "The Lawyer Looks at the Law", "The Poet Looks at Civilization", etc., etc. I might have followed their precedent by naming this lecture "The Physicist Looks at the Ionosphere". Better would have been to say "The Physicist Listens to the Ionosphere"; for while the actual procedure is neither listening nor looking in the usual senses, it is rather more like listening. As a matter of fact we have all of us listened to the ionosphere—all of us excepting those who as yet have never hearkened to a broadcast from long distance, and who must by now be few. Any program which is heard from more than a few hundred miles, and does not come by wire, comes by courtesy of the ionosphere. When we are lending ear to such a program, we are listening both to the loud-speaker and to the ionosphere, since both take part in the transmission. Of course we are likely to be listening also to the news; but nowadays the news is generally dismal or frightful or both; and it should be happiness to be diverted for a while from what the ionosphere brings to the qualities of this innocent agent itself, which is not in the least to blame for the evil which it reflects.

I suppose it would be logical to begin by expounding the mathematical theory, to describe next the techniques of experiment, and so come finally to the results. This would, however, be a long hard path, and we should be in danger of wasting much effort in exploring mathematical byways traced in the expectation of results which have not as yet been attained. The order will therefore be as follows: first a statement of some of the main results, then a glance at the experimental methods, then a brief but not particularly easy excursion into the theory, and finally a return to the results with as much additional detail as the space will allow. Now I will call at once upon the illustrations to supplement my words.

Figure 1 shows a segment of the surface of the earth, and on it an aerial which is engaged in emitting wireless waves. The vertical lines rising from the surface are meant to indicate the wave fronts of the energy which is radiated horizontally or nearly so. They are so drawn as to show this "ground wave", as it is called, dying out within a few hundred miles of the starting point. If we could hear only by means of the ground wave, this would mark the limit of transmission. But above, run lines to indicate the paths of the energy radiated in various upward directions; and there is something which reflects them, so that they return to the earth. It is this something, this reflector for radio waves, this electrical mirror over the earth, which concerns us.

This mirror is what for the last few years has borne the name of "ionosphere". The former name was Kennelly-Heaviside layer; for Kennelly and Heaviside—there is no need of recalling who they were—having been impressed by the fact that the ground wave dies so early, came independently to the conclusion that in the upper air there must be a conducting layer to send back the upward-headed waves. That was in 1902, a time at which the notion of conductive air was almost revolutionary. Ordinary air, as we all know, is a very good insulator; Kennelly and Heaviside were supposing that at high altitudes this quality would be reversed, which was a rather daring speculation. Five years earlier than 1902, it might have been too daring for anyone to risk; but by 1902, people were beginning to know and to understand that ultraviolet light has the power of converting non-conductive air into a conductor by detaching electrons from the molecules thereof. Well, there is certainly plenty of ultraviolet light falling out of the sun into the high atmosphere, though very little of it ever gets down to the depths where we live; so here, at one stroke, I have stated our present idea of the ionosphere, and also our idea of the principal agent which makes it what it is. Sunlight, perhaps with the aid of other agents as well, converts the upper atmosphere from an ordinary gas of neutral molecules into a mixture of two electrified gases with one which is neutral. One of the electrified gases consists of free electrons; the other consists of the positive ions which are the molecules from which the electrons were torn; while the neutral gas consists of the molecules which as yet are unaffected. This is the simplified picture which I wish now to substantiate in the main, but of which I must also point out in due time some of the flaws.

Perhaps there are some among you who will think it strange that a mere gas—especially a very rarefied gas, and particularly a gas composed of particles as light as electrons—should serve as a mirror. Would it make you any happier, if I were to say that up in the sky there is a smooth hard ceiling like that imagined by the Greeks, made, for example, of nicely polished and perfectly reflecting

A lecture delivered at a meeting of the AIEE New York Section, February 27, 1940.

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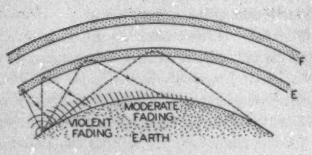


Figure 1. Trajectories of radio waves, with oversimplified model of ionosphere (after Mimno)

silver? Well, I shall say nothing of the sort; but instead I will say that when visible light is reflected from a hard solid mirror of silver, it is not the hardness of the silver which is doing the reflecting, but just another electron gas which is diffused through the pores of the metal! A metal mirror is a container for an electron gas, but here in the upper air we have an electron gas without a container, and both of them are able to reflect. Later on I will show you some of the equations for their reflecting power, but we are not yet finished with figure 1. I want now to use this figure to show how the elevation, the altitude of the electronic mirror over the earth can be determined.

One way of measuring this altitude is very obvious—if, that is to say, it will work. Suppose that the observer is able to go a measured distance away from the aerial and measure there the angle which the reflected wave or "sky wave" (as it is called, to distinguish it from the ground wave) makes with the vertical as it comes down to him. If this can be done, then evidently he can get the altitude by the simplest trigonometry. It *can* be done, and it was done by Appleton and Barnett in 1925.

Another scheme is much more complicated, and I can give only the merest glimpse of it. It is a clever way of putting to useful service the very great inconvenience which the radio people call "fading". They have a curious usage for this word: to me as a physicist or as a writer, "fading" suggests a signal which dies out and never returns, but to a radio engineer it seems to mean a signal which dies out and then comes back again and keeps on doing this over and over again, in a most irregular fashion. This sort of thing happens in the regions where the ground wave and the sky wave both arrive and overlap one another, and it is due to what in optics is called the "interference" of the two waves. If conditions were absolutely stable, then in taking a little walk one would pass through several maxima and several minima of intensity. Since conditions are never absolutely stable, the observer need not take the walk; even while he stays at a fixed point, the maxima and the minima just float past him as the electronic mirror wiggles up and down in the sky. Now suppose him standing still, at a moment when the conditions are relatively stable; and suppose that the engineer at the sending aerial changes the wave length by a small and known amount; several maxima and minima will float right past the observer, and by counting them he can (though this is not at all obvious!) get a datum which will enable him to figure out the altitude of the reflecting layer in the sky. This method also was invented by Appleton, and can be found explained in the literature under the name of "wave-length-change method".

The third method is the only one which henceforth will figure in these pages. It is the "method of echoes" (sometimes called by the clumsy name of "group-retardation method"). This was invented and first applied at the Carnegie Institution of Washington by Breit and Tuve.

To introduce it I recall that in figure 1, the two bands represented layers populated with electron gas; and now I call attention to figure 2*A*, which is a graph of the density or concentration of that electron gas—*N* electrons per cubic centimeter—plotted against elevation over the ground. (By the way, whenever I speak of the distance of anything above the ground, I intend to use the words "elevation" or "altitude", so as to reserve the word "height" for the heights of peaks on curves; thus the words "height" and "high" shall always be taken in reference to curves, and never in reference to distance up in the sky.)

It is evident that if figure 2*A* corresponded exactly to figure 1, the curve would consist of a pair of square-topped rectangles. But as almost every reader must have guessed, figure 1 was oversimplified, and whatever the truth may be, figure 2*A* with its smoothly bending curve must be closer to it than figure 1. Figure 2*A* looks like the cross section of two mountain ranges; and there are places and times of day when there would be four distinguishable mountain peaks instead of only two.

Now I am going to hold to this naïve metaphor of mountains for a little while; and first I will ask you to imagine that you are looking, from a great distance on the left, onto actual mountains like these. In such a case you would never see the valleys between the mountains, and of each peak beyond the first you would see only just so much as might rise above the peak next preceding it. The first point to be made is that the echo method suffers from the same limitation, and that is why the parts of this curve which slope downward to the right are shown in dashes; the data say nothing about them.

Of course if you were actually looking at earthly mountains, you would be seeing them by light which comes from the sun and is reflected by them to your eyes. Once in looking up the early history of optics, I came upon the idea of some Greeks who believed that light is something which springs from the eyes of the looker, races over to the object to be looked upon, and then comes back to the looker's eyes bringing its report. The idea is ascribed to the Pythagorean school, and also to others who may or may not have had it from Pythagoras. Well, I wish that Pythagoras could be with us now, for he would certainly be pleased to discover that all unwittingly he had fore-

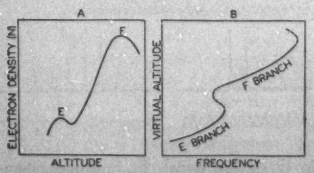


Figure 2A. "Curve of inference": conjectural dependence of number *N* of electrons per unit volume on true altitude *h*

Figure 2B. The "curve of data": dependence of virtual altitude *h'* of ceiling (one-half the delay of the echo, multiplied by *c*) on frequency *f*

seen the present-day method of looking over the ionosphere. We use invisible light instead of visible, and the waves spring from our apparatus and come back to our apparatus instead of springing from and coming back to our eyes; but the principle is the same, and that is what is signified by the name of "echo method".

Now let us recall for a moment how acoustic echoes would behave, if instead of looking from the left at this mountain range, one were shouting at it with an enormous voice. After a while one would get an echo from the front side of the smaller peak, and after a longer while, a second echo from the overtopping part of the larger peak. One could measure the lapses of time between the departure of the shout and the arrivals of the two echoes, multiply it by the speed of sound in air, and the products would be the doubled distances from the shouter to, roughly, the midway points of the slopes. Some of the early work on the ionosphere by the echo method was not very different from this, and presently I will show you the traces of such pairs of echoes. However, the method is very much more subtle, because of a feature not exhibited by acoustic waves. I am now going to lead you for a couple of minutes into an imaginary world where sound waves *do* have this feature, to show you how strange it is.

Imagine then that the laws of sound are so strangely devised, that every pitch is reflected from one particular height on the mountainside, and the shriller the pitch, the greater the height of reflection. A basso profundo, we will imagine, will then be echoed from the bottom of the first peak; a baritone from its middle; a tenor from near its top; the voice of a contralto might slip over the summit of the lower peak and be reflected from the taller, the voice of a sufficiently high soprano might go over both and never be echoed at all. Imagine further that in this remarkable world you have the entire cast of an opera at your disposal, and order them to sing their scales from the very bottom bass to the very topmost soprano—and listen for the echoes. As the voices clamber up the scale, the echo will be more and more delayed, but at first the change will be gradual. Suddenly however will come a pitch—I suggested that it would occur somewhere between tenor and contralto—where the delay of the echo will suddenly and sharply rise; and this will be the pitch corresponding to the height of the first peak. Later on there will come a pitch—somewhere in the high soprano—at which you may listen forever, and yet the echo will not come back. This corresponds to the height of the taller peak. If you knew the relation between frequency and height of reflection, you then could figure out the heights of both the peaks. Indeed you could even make a tracing of their slopes, except in the valley between; but now it is time to lay aside this simile, and go back more closely to the data.

The curve of figure 2*A* (to repeat) is a crude conjecture of the trend of the density N of electrons in the ionosphere plotted against the altitude h over the ground. Now think of a beam of wireless waves of some definite frequency f mounting up through the air—mounting *vertically*, let us suppose, since it is thus that most of the experiments are done. The beam will penetrate the ionosphere until it reaches an altitude where the electron density has a certain particular value depending on f. Here it will be echoed—reflected—turned back and sent back to the earth. The electrical mirror of my first analogy is located, for this particular frequency but only for this one, at the altitude where this particular electron density is found; and therefore I will call the latter "the mirror density," $N_m(f)$, for the frequency f. Where the density attains the value $N_m(f)$, there the waves of frequency f find their mirror. Densities less than the mirror density will let the waves go through. Greater densities would stop them indeed, but do not get the chance, being ordinarily underlain by strata where the density has the mirror value precisely.

In going up to the mirror level in the ionosphere and coming back therefrom, the signals take an appreciable time. Please note the replacement of "waves" by "signals" in that phrase! It is of the first importance. If one were to send a steady long-continuing wave train into the sky it would be of no use, for one would not be able to distinguish its echo from itself. The wave train must be interrupted so that there is nothing left of it but one or a series of pieces—the "signals", "pulses", or "groups"—each of which goes forth as an entity limited in time and is echoed back as such an entity. The speed of such a signal or group is not the same as the speed of the waves, a paradox which is one of the stumbling blocks of physics. It is the group speed v which determines the time of going and returning, the "delay of the echo" as I will call it.

I do not wish to imply that this "delay of the echo" would be appreciable on an ordinary clock! It is of the order of milliseconds, as one sees in figure 3 which will make the echoes vivid in the reader's mind. Here we see sharp sudden deflections or kicks made by an oscillograph in the receiving device. The kicks marked G are the signals just departing from the sender; the rest are echoes. Those marked with subscripts 1 . . . 5 have been reflected one to five times from the ionosphere, all but the first having been re-echoed from the ground.

In studying the ionosphere, one measures the delay of the echo for as wide a range of frequencies as one's apparatus will allow, and so the data come out in the form of a graph with frequency of waves and delay of the echo plotted one against the other. The curve of figure 2*A* is a curve of inference; but now, proceeding in just the opposite direction from the investigators, I am going to take

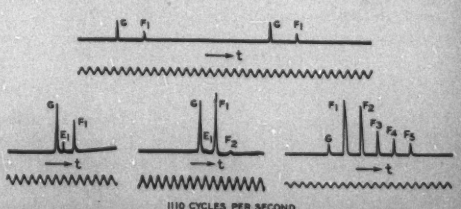


Figure 3. Echoes: G, original signal; E_1, F_1 echoes returning after a single reflection from E and F respectively; F_2 . . . . F_5, echoes which have suffered two to five reflections at F layer (Appleton and Builder)

you backward from this "curve of inference" to the forthcoming curves of the data.

Evidently, if mirror density were exactly proportional to frequency, and if delay of the echo were exactly proportional to altitude of the echoing layer, we should have just the same curve over again with different symbols and scales along the axes. But the relations are not nearly so simple, and so the curve of data is distorted from the curve of inference.

In the first place, mirror density is proportional not to the frequency but to the square thereof, as I will soon be proving. The distortion due to this is easy to allow for.

But in the second place, the delay of the echo cannot be proportional to the altitude of the echoing layer unless the speed of the signal is constant; and this is not so. While the signal is voyaging through those regions of the ionosphere where the electron density is already high though not so high as the mirror value, its speed is reduced, and often reduced considerably. This *is* a tough distortion to allow for, since it depends not on things already known but upon the very thing one is striving to find out, to wit, the distribution of electron density in the ionosphere! The problem is somewhat like having to solve for x an equation in which x appears badly entangled in both members of the equation. There will shortly be an occasion for saying a little more about this distortion; for the moment I will mention only that in spite of it the curve of the data retains the major features of the curve of inference.

To sketch the curve of data, then, one would begin by making a rough copy of the curve of inference with its shorter and its taller peak. But to come into harmony with usage, one must turn the axes through 90 degrees, so that delay of echo shall be plotted vertically and frequency along the horizontal axis. Now the peaks are lying on their sides; and now it is easy to see, in virtue of what I was lately saying, that in the curve of data they appear just as two separated branches with a gap between. For imagine the observer making his tests by going step by step from low frequencies toward high; the points depicting his observations will lie first along the slope of the shorter hill, then jump to the taller hill and follow along *its* slope till its own peak is reached, and then there will be no more, for the echoes will have ceased. Figure 2*B* is drawn with the observable branches of the curves heavily scored, the unobservable parts reduced to chains of dashes.

We shall see very soon that the curves of data are recognizably like that of figure 2*B;* but beforehand I ought to acquaint you with some technical terms and some further details.

Now that the peaks are lying on their sides we call them "layers", coming thus into conformity with usage and with the facts, for of course they stand for horizontal strata of ionized air. Thus far we have distinguished two of them; the one nearer the ground is called the E layer, the one further up in the sky is lettered F. (The names Kennelly-Heaviside and Appleton for E and F are sometimes seen.) The branches of the curve of data which lie to left and right of the gap may be considered as the profiles of the undersides of these layers, subject to the distortion to which I have already alluded. I will call them E branch and F branch, though this is not a general usage. At the right-hand end of the E branch is the highest frequency which finds a mirror density in the E layer, and at the left-hand end of the F branch is the lowest frequency which can penetrate the E layer and so reach on to F. The latter must be infinitesimally higher than the former, but in practice one does not draw this fine distinction, and the names "penetration frequency of the E layer" and "critical frequency of the E layer" and the symbol f_E are applied to them both indiscriminately. Similarly, the right-hand end of the F branch shows to us the penetration frequency of the F layer. There are times of day and year when the curve of the data may be composed of three or even of four branches, indicating as many distinguishable layers; these are then denoted by E_1 and E_2, F_1 and F_2 in order of increasing altitude. It is clear that the notation is in danger of becoming cumbrous, should any more layers ever be identified among those already lettered.

One more detail: The customary ordinate, in such graphs as we are about to study, is not T the delay of the echo but one-half of cT the product thereof by c the speed of light in vacuo. This is the altitude which one would assign to the mirror level, if one could believe that the signal travels to and fro with the speed c. It is denoted by h', and is called "equivalent height" or "virtual height": I will call it "virtual altitude" so as to preserve the distinction between altitude and height which I am trying to keep in this lecture. It is always greater than the actual altitude, since the signal always travels with a speed lower than c; the difference is the complicated distortion which I mentioned above. Now that we have encountered again this distortion, I will state one of its important features. The distortion, or in other words *the excess of virtual over actual altitude, is greatest for frequencies close to the critical frequency of a layer:* for signals of these frequencies must travel through regions where the electron density is close to the mirror value, and this is the condition for the maximum of slowing-down. It is easy to see that owing to this feature of the distortion, the natural uptrend of the right-hand end of every branch (due to the fact that actual altitude of mirror level increases with frequency) will be exaggerated. Moreover (and this is worse) the left-hand end of a branch is likely to show a downtrend which in a curve of actual altitude against frequency would not be there at all. And now at last we turn to actual examples of (h', f) curves, as these curves of the data are called by Appleton.

Figure 4 is taken from the immensely extensive work of Appleton and his school. As happens so often in expositions, the reader has not yet been prepared for all the detail which it shows; I must ask him to ignore for the present the curve marked with crosses, and fix his attention on that with the circles. Here he will see the E branch, the gap, and the F branch deformed by an enormous hump or crinkle before it finally sweeps upward toward its critical frequency. It is supposed that the crinkle would be another gap, but for the distortion which has

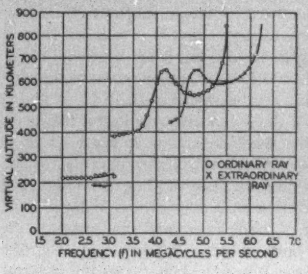


Figure 4. Example of characteristic or (h', f) curves, showing gap between E branch and F branch, and crinkle in F branch indicating presence of F_1 layer. Duplication of curve due to earth's magnetic field (Appleton)

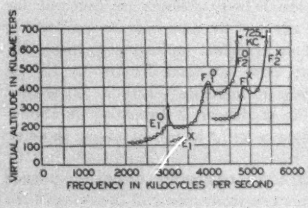


Figure 5. Another example of (h', f) curve, showing gap and crinkle (Schafer and Goodall)

twisted the curve upward from both sides toward the maximum. It is therefore taken as evidence for an additional peak, or perhaps a ledge or terrace on the side of the main F peak; to this peak or terrace or ledge the symbol F_1 is applied.

Figure 5 is a similar curve from Bell Telephone Laboratories, showing the gap, the crinkle, and the curvatures which on the left of every branch are wholly and on the right are partly due to the distortion.

So great is the interest in curves like these, and so much do they vary from time to time and from place to place, that lately (according to Appleton's count) there have been more than a score of stations over the world engaged in making them. At some of these productiveness has been enhanced and toil reduced by a machine developed at the Bureau of Standards and the Carnegie Institution. Automatically sending out the signals ten times in a second, and changing the frequency by (on an average) 1,600 cycles between each signal and the next while the photographic film is moved by a tiny distance from right to left, this "multifrequency apparatus" traces the curve of h' against f over the frequency range between 0.516 and 16 megacyles in 15 minutes and then goes back and does it all over again and again.

Figures 6, 7, and 8 show curves thus automatically taken, selected for bringing out one feature or another. In figure 6 are curves with crinkles in the F branch, recalling Appleton's of figure 4. In figure 7, however, the crinkle is missing, and the F branch sweeps smoothly and slowly upward from its commencement, forking before the end. Many observations have concurred in showing that the crinkle is present only when the sun is high in the sky, therefore absent by night and at the beginning and end of day, and indeed absent *all* day in winter where the latitude is high. This is our first example of the dependence of the ionosphere on sunlight, a very important feature! In all of these figures the curves are repeated several times along the vertical direction. This indicates echoes which have traveled four, six, eight or more times between earth and ionosphere, being reflected at both ends of the path; the earth below is a mirror like the free electrons above. Figure 8 shows a wonderful multitude of such echoes.

The curves of figure 9 are sketches based upon many. Contrasting those on the left with those on the right, we see the crinkle prominent in the ones, missing or faint in the others. This is the difference between summer and winter. All of the curves were taken near noon, but though the District of Columbia is not precisely in polar latitudes, the sun in December does not rise far enough in Washington's sky to bring out that feature of the ionosphere of which the crinkle is the sign. Running the eye up either column, one sees the curve lengthening out to the right as year follows year. During this sequence of years the sunspots were steadily growing more frequent: The sun was in the ascending part of that 11-year cycle of its fever, of which the sunspots are one of the manifestations, while the form of these curves is another.

Having seen so many curves which are either doubled or forked, the reader has a right to know the cause of forking and doubling in advance of due time. It is the magnetic field of the earth. Were I to attempt to give the theory thereof along with all the rest, this lecture would be transformed into a treatise. I dare not venture on more than the basic theory, with subsequent brief mention of what is done to it by the magnetic field and another complicating factor. Leaving these for the present aside, I now exhibit the basic theory by deriving *the formula for computing the mirror density from the reflected frequency*.

To situate this formula correctly in the frame of theoretical physics, I must go back to Maxwell.

The famous equations of Maxwell, when treated in a way which we all have been taught (or should have been) melt together into a wave equation. The waves which it describes consist of an oscillating electric field which I will

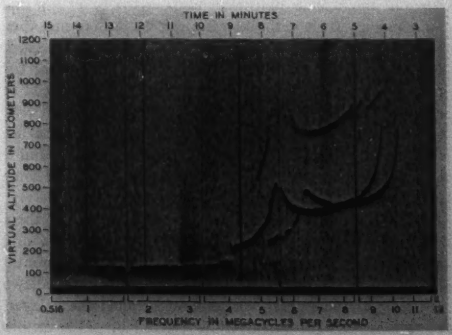


Figure 6. Characteristic (h', f) curves obtained with multifrequency sweep apparatus, sun high in sky, F_1 crinkle apparent (Carnegie Institution of Washington)

call $E_0 \sin nt$, and also of an oscillating magnetic field which for the present purpose we are allowed to ignore. When of high frequency, these are the waves of light, as Maxwell knew; when of low frequency they are the waves of radio, which Maxwell never knew because of his premature death some years before they were produced. In the wave equation describing these waves, there occurs of course the wave speed; I will call it u. Here then is the great idea of Maxwell: *The square of the wave speed varies inversely as the current density provoked by unit amplitude*[1] *of the oscillating field.*

Now we see at once that in the ionosphere the wave speed must be affected by the presence of the free electrons, since they are set into oscillation by the waves and therefore contribute to the current density!

At this point, those of us who were educated in the electronic era—and that is a class which probably includes most of the audience—are in some danger of falling into a

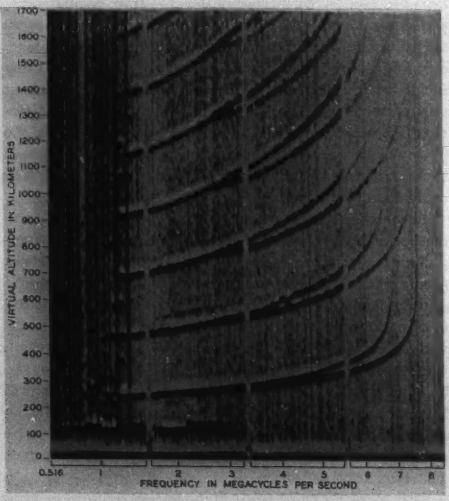


Figure 7. Characteristic (h', f) curves obtained with the multifrequency apparatus: sun low in sky, F_1 crinkle missing (Carnegie Institution of Washington)

serious error. We may in fact assume that the electrons constitute the whole of the current, and therefore deduce that in vacuo the oscillating field provokes no current at all, and hence that the wave speed in vacuo is infinite—which is absurd! Maxwell was wiser. He understood, and he put it down in his theory, that wherever there is an electric field which is changing with time, the rate of change of that field is equivalent to a current density. This he called the "displacement current" and for the case of vacuum he said that the displacement-current density is precisely equal to the rate of change of the field, multiplied by one of those tiresome factors $1/4\pi$ that are always

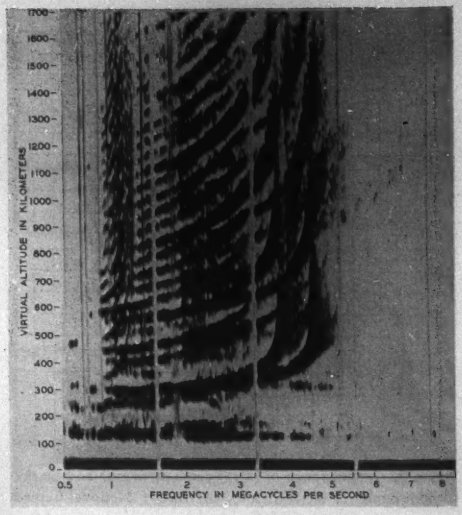


Figure 8. Multiple echoes (Carnegie Institution of Washington)

popping up in the electromagnetic theory (although in some unit-systems they are few). In the vacuum therefore there is a current density $(1/4\pi)$ times the rate of change of $E_0 \sin nt$, and it therefore has an amplitude of $(1/4\pi)nE_0$ and is 90 degrees ahead of the field in phase. To this current density corresponds the speed of light in vacuo, the well-known constant c.

When the waves pass out of vacuum or out of ordinary air into the ionosphere, we still have the displacement current but now in addition we have, superposed upon it, the current of the electrons. Here is a second pitfall. It may seem obvious that the electron current must add on to the displacement current, creating a total current density greater than that in vacuo and therefore lowering the wave speed. Not so at all! The point is, that when the electrons are truly free, the field sets them into oscillation in such a curious way[2] that when they become adjusted, they are oscillating with their velocities 90 degrees behind the field in phase. Their contribution to the current, being proportional to their velocity, is also 90 degrees behind the field, and hence in perfect opposition of phase to the displacement current. Therefore the electron-current density—call it I_e—is to be *subtracted* from the displacement-current density! Accordingly I write

$$\frac{u^2}{c^2} = \frac{n(1/4\pi)E_0}{n(1/4\pi)E_0 - I_e} \qquad (1)$$

The reader may suppose that the factor $\sin nt$, common to

1. I introduce the words "unit amplitude" to save the reader from drawing the erroneous inference that wave speed depends upon wave amplitude.

2. Well known, however, to anyone who has studied the theory of simple harmonic motion.

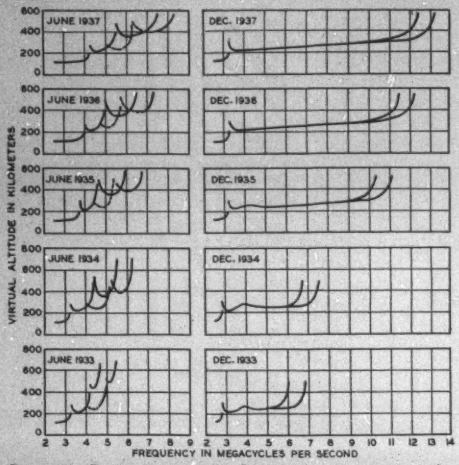


Figure 9. Dependence of (h′, f) curve on season and on the sunspot cycle (Smith, Gilliland, and Kirby: National Bureau of Standards)

both currents, has been divided out.[3] The quantity I is clearly proportional to E_0 and also to our familiar N the density of electrons, and in fact the reader can undoubtedly work out with ease that it is equal to NE_0e^2/mn (Here e and m stand for the charge and mass of the electron, as is customary). Therefore we find:

$$\frac{u^2}{c^2} = \frac{1}{1-4\pi Ne^2/mn^2} = \frac{1}{1-Ne^2/\pi mf^2} \qquad (2)$$

The wave speed is greater in the ionosphere than it is in vacuo or in ordinary air. (The speed in ordinary non-ionized air is so nearly equal to c that we shall always ignore the difference.)

I pause to give the reader one more warning against confusing the speeds of wave and signal. The signals do not travel with this speed which is greater than c (if they did, the theory of relativity would be sunk!) but always at a rate[4] inferior or at the most equal to c. Now take note that equation 2 affirms that if ever N should be equal to $\pi mf^2/e^2$ the denominator on the right would vanish, obliging wave speed to be infinite! Of course it is not uncommon in theory for an equation to propose for some physical quantity under certain conditions an infinite value, which in practice has no meaning because the conditions can never be realized in nature. This is no such case. When frequencies usual in radio are inserted for f, the values of $\pi mf^2/e^2$ are perfectly plausible ones for N to have; and therefore we must reckon with the vanishing of that denominator. To show what that vanishing must mean, I will recall the refraction of light between, say, air and water.

In figure 10 the water is shown as lying underneath the air, not only because that is how it generally lies in nature, but also because the sketch will now fit both sides of the analogy. Passing from air into water, a beam of light is refracted—as everyone knows—toward the normal or vertical. This is because the wave speed of light is smaller in water than in air. Passing from water into air, as the arrow suggests, the beam AOA' is refracted away from the normal, for now it is going into a medium where the wave speed is higher than in the medium which it is quitting. For the very same reason the radio beam, mounting from the lower atmosphere to the ionosphere, is refracted away from the vertical.

Contrast, in figure 10, the beams AOA' and BOB'. Below the boundary they differ in their inclination to the vertical; above, the difference is greater, because of the law of refraction (Snell's law of sines). If we go on making the incident beam more and more slanting, we come eventually to one which is refracted into the horizontal plane: it is COC' in the sketch. Any beam of still more slanting incidence will not be able to enter the upper medium at all; perforce it will suffer "total reflection." The direction CO may be regarded as the dividing line between the rays which can get through into the upper medium, and those which definitely cannot. The angle $C'OZ'$ is a critical angle of incidence.

The critical angle of incidence depends on the ratio of the wave speeds in the media. When these are water and air there is very little we can do to alter the speeds or their ratio. Let us, however, imagine ourselves possessed of some technique for altering wave speed ad libitum, and using it to make the speed in the upper medium increase without limit. As it increases, the critical direction will turn more and more toward the normal to the boundary. The beams which can pass through will be restricted to a smaller and smaller compass. If the critical direction arrives at the vertical, none at all will be able to pass through: even the normally incident waves will suffer total reflection.

Well, when the wave speed in the upper medium becomes infinite, the critical direction *does* arrive at the vertical! This is what happens when N rises to the value $\pi mf^2/e^2$. *Total reflection of the waves becomes unavoidable even for vertical incidence when the condition*

$$N \geqq \pi mf^2/e^2 \qquad (3)$$

is fulfilled. Or, to turn the equation around: Penetration of the medium by the waves is possible when and only when the condition

$$f \geqq \sqrt{Ne^2/\pi m} \qquad (4)$$

is fulfilled.

Leaving out the inequality sign from either formula 3 or 4, we have the *equation for the penetration frequency*, $f=\sqrt{Ne^2/\pi m}$ the relation between mirror density and wave frequency at which I have so long been hinting. As the manner of its derivation has now made evident, it

3. Actually Maxwell's theorem does refer to the amplitudes of the currents—but if the currents are not exactly 0 or 180 degrees apart in phase, the amplitude of one must be taken as a complex quantity.

4. When u depends on f in the manner of equation 2, the group speed (which is an approximation to the signal speed) is equal to c^2/u. By a strange but quite fortuitous coincidence this is similar to the relation prevailing between wave speed and group speed for the "de Broglie waves" associated with material particles.

refers to *vertically rising* waves. These are mainly used in the experiments for sounding the ionosphere, as one may say. But if the wireless is being used for communication over broad distances, it is the case of obliquely rising waves which occurs. For these the mirror density is reduced, in a manner easy to work out—though not so easy as it would be if the earth were flat; for actually the ionosphere follows the curvature of the earth, and this must be taken into account.

What values of N are given by the data, interpreted with the aid of formula 3?

This is a question which it is not well to answer too precisely. One might say that whenever an echo is observed on a frequency f, there must exist somewhere in the ionosphere an electron-density N related to f by formula 3. This is probably too strong a statement. The literature is full of allusions to mystifying echoes, some at least of which indicate that often the electron density at a given altitude varies rapidly from place to place (so contradicting one of our basic assumptions). Also it is almost certain that many echoes are due to partial reflection (as distinguished from total) occurring where N is increasing rapidly with altitude though its mirror value is not reached.[5]

One does well therefore to start from a good clear (h', f) curve, such as those of the figures, and calculate the N values for important points along it. But which shall we consider the "important" points? Those corresponding to special altitudes, such as 100 and 200 kilometers or those corresponding to special frequencies, such as penetration frequencies or the top of the crinkle in the curve of figure 7? The latter is the general practice, and therefore I follow it. The N values about to be given are those corresponding to presumptive maxima along the "curve of inference" of figure 2, to gaps or crinkles in the "curves of data." They are those of what I will call the "crowns" of the various layers (not the "tops," since there is no reason for supposing that the electron density falls suddenly to zero just above the points where it passes through maxima).

At Huancayo in the Peruvian Andes, then at a typical summer noon, N has the values $1.8 \cdot 10^5$—$3.3 \cdot 10^5$—$1 \cdot 10^6$ at the crowns of the layers lettered E, F_1 and F_2; so says Berkner. At Slough near London, at noon on a certain day of early spring (1933) Appleton found $1.2 \cdot 10^5$ at the crown of E and $3.8 \cdot 10^5$ at the crown of F, the F layer being at that time and place not differentiated into F_1 and F_2. These figures are not far apart, if E be compared with E and F_1 with F; but with a little search I could have found

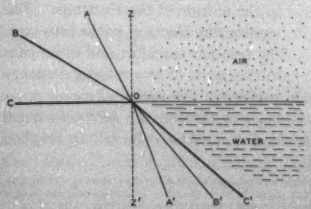
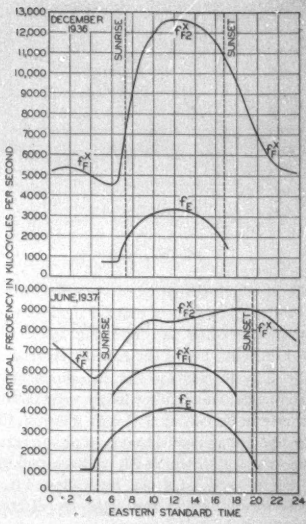


Figure 10. Diagram illustrating refraction and total reflection

Figure 11. Dependence of critical frequencies on season and hour of day (Smith, Gilliland, and Kirby)



plenty of values differing much more greatly, as is attested by figures 9 and 11.

From figure 9 we have already deduced that critical frequencies vary as the sunspot cycle proceeds; I now add that from minimum to maximum of the cycle just now ending, N at the crown of the E layer increased by three-fifths while N at the crown of F_2 went up (in winter) no less than fourfold!

From figure 11 we observe how great is the change of these N values with hour of day. True, the ordinates here are critical frequencies rather than values of N. The reader might convert them into N values; but the magnetic field of the earth is already intervening in these data and altering formula 3, and there is in fact another source of doubt;[6] so on the whole it is better to follow the slightly contradictory policies of regarding the critical frequencies as indications of electron density but of quoting them for themselves.

I therefore summarize, as precisely as seems justifiable: The N values at the crowns of the layers vary with hour of day and time of year and year of the sunspot cycle very markedly, and 10^5 to 10^6 electrons per cubic centimeter is a good figure to retain in mind for the order of magnitude thereof. As closing exhibit of this section I show figure

5. According to theory this should occur whenever N varies by a considerable percentage over a distance of the order of a wave length. Experiments show numerous instances of (h', f) curves in which the E branch extends for quite a way beyond the beginning of the F branch (e.g. figure 14; also figure 3 exhibits E and F echoes of the same signal). The occurrence of the E echo under such conditions is sometimes ascribed to partial reflection, sometimes to limited swarms or "clouds" of electrons which reflects portions of each signal while other portions slip between them and go on to the F region.

6. I refer to the fact that there is no consensus of opinion as to whether the field acting upon each individual electron is truly $E_0 \sin \omega t$ as I wrote it on a preceding page, or is $E_0 \sin \omega t$ modified by a contribution due to the other oscillating electrons. This is a special case of one of the most frequent and difficult questions in physics (another special case being the question: What is the magnetic field within a magnetized body?). It would take much too much space to analyze or even to describe the arguments advanced: I will merely say that in the belief of some, the factor 3/2 should be multiplied into the right-hand member of (3).

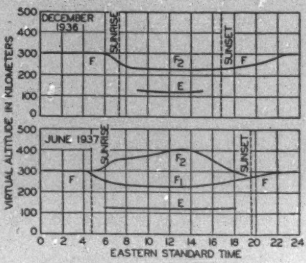


Figure 12. Dependence of virtual altitude of the crowns of the principal layers on season and hour of day (Smith, Gilliland, and Kirby)

13, in which the delay of the echo for a certain frequency (two megacycles) is plotted against the time during the hours preceding and following dawn. Interpret with the aid of figure 2 and the context thereof: During the night the E peak was too low to echo back the pulses of this frequency, which accordingly went farther and found their mirror in F; but at 6.35 a.m. sharply, the E peak attained to a height sufficient to intercept and return them. Or lest the distinction which I have been trying to make between "height" and "altitude" have slipped from memory, put it this way: During the night the electron density at the crown of the E layer was inferior to the mirror density for f=two megacycles, but during the dawn it was increasing and at 6.35 a.m. it reached and passed that mirror density.

Now to speak for a moment of altitude: Our procedure shall be as in the case of N—we regard virtual altitudes as indications of actual altitudes, but quote them for themselves. Figure 14 shows the virtual altitudes of the crowns of the layers, as they vary with hour of day in summer and winter, in the sky over Washington, D. C. It is evident that E is a fixture of the ionosphere at 120 kilometers or thereabouts, but F rises and falls in the course of a winter day, rises and falls and divides and merges again during a day of summer.

Now we must take brief notice of a difficult subject: the forkings and the doublings of the (h', f) curves, and the theory which finds their source in the earth's magnetic field.

A magnetic field, the earth's or any other, should have no effect whatsoever on radio waves so long as these are traveling in air composed entirely of neutral molecules. When, however, the waves are setting electrons into motion, the moving electrons are affected by the field, which has a twisting action on their paths. We have seen already that the moving electrons react, so to speak, upon

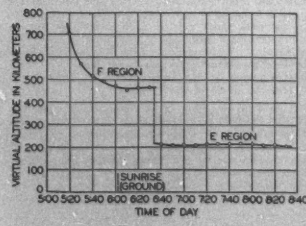


Figure 13. Ceiling for signal of fixed frequency shifting near sunrise from F to E as the electron density of the E layer increases with increase of light (Appleton)

the waves, raising the wave speed thereof. By altering the motions of the electrons, the magnetic field will influence at second hand the waves themselves. But will the result be perceptible? In view of the fact that the earth's magnetic field is very feeble by comparison with the fields between the poles of our electromagnets great or small, or even with those around the horseshoe magnets which are playthings, one might well think the influence not worth the trouble of computing. But those who first undertook to compute it—Nichols and Schelleng in America, Appleton independently in England, in the winter of 1924–25—found it a serious influence, and very well worth the trouble.

The problem is one of those which are not very hard to state, but can be very tedious to solve except in special cases which may or may not be of practical importance. For this problem it happens that two of the special cases can be solved with relative ease, and one at least is realizable in practice. I cannot venture to give the theory of even this one, but at least I will attempt to describe what happens.

The special case occurs when the waves are traveling at right angles to the field. Since they travel vertically,[7] it is necessary to find a place on the earth where the field is horizontal. Such places are found in the equatorial regions only, and these are not precisely crowded with universities or engineering experiment stations. However the Carnegie Institution of Washington was inspired, several years ago, to set up a station in just such a place: Huancayo, in the Andes of Peru. Here they established long straight horizontal antennas, one running north and south, another east and west, and yet another northeast and southwest. In the waves which mount from these to the ionosphere and then come bouncing back, the electric field $E_0 \sin nt$—henceforth to be called "the electric vector"—is faithful to the direction of the antenna. They are called "plane-polarized waves."

When the north-south antenna is used, the electrons are impelled to and fro in the north-south direction which is that of the magnetic meridian. Now as is well known, an electron moving parallel to a magnetic field behaves just as it would if there were no such field at all. These waves ought therefore to behave according to the theory which we set up while we were still disregarding the magnetic field. They are the so-called "ordinary waves" or "o waves."

When the east-west antenna is used, the electrons of the ionosphere are impelled to and fro in the east-west direction, which is transverse to the earth's magnetic field. This is just the condition for the maximum amount of meddling by the field in the motion of the electrons. The meddling consists in bending the electron paths into curiously twisted arcs. The result is singular, and quite contrary to what one's intuition says, or at any rate, contrary to what my intuition told me. *The action of the magnetic field is tantamount to strengthening the electron-current density I, parallel to the electric vector.* It will be recalled

7. In addition to the other advantages of sending the waves up vertically there is the feature that the angle between their line of motion and the field is the same when they are going up and when they are returning.

(from a preceding page) that it is I_e which for small N values cancels a part of the displacement current and so speeds up the waves, and for a certain critical N value cancels the whole of the displacement current and so brings about total reflection. So, for these "extraordinary waves" or "x waves," a given N value produces a greater augmentation of the wave speed, and the critical N value for total reflection is smaller than for the ordinary waves. The signal composed of x waves, mounting into the ionosphere, finds its appropriate mirror at a lesser altitude than does the signal composed of o waves, and it gets earlier back to earth. It may indeed come back from E while the o signal goes on to F or from F_1 while the o signal goes on to F_2, or from F_2 while the other goes irretrievably forth into space.

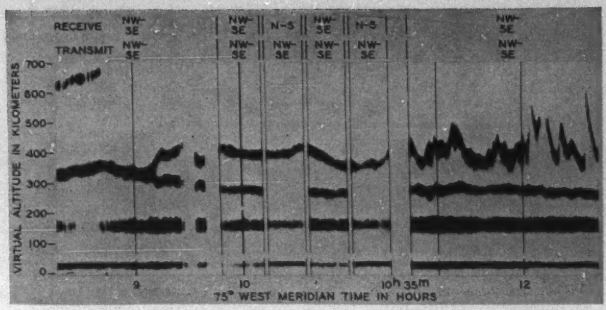


Figure 14. Echoes of plane-polarized signals (Wells and Berkner)

When the northwest-southwest antenna is used, the ionosphere takes charge of the signals, and separates them into an o component and an x component. Each travels according to its proper law, and the x component reaches its lower-down mirror earlier and beats the o component back to earth. Two echoes return instead of one. The earlier is plane-polarized with electric vector east and west, the laggard is plane-polarized with electric vector north and south. Suppose a long straight horizontal antenna is used to respond to the returning signals. It will respond to both, if pointed northwest-southeast; only to the earlier, if pointed east and west; only to the later, if pointed north and south.

All the foregoing were statements of theory at first, but thanks to the experiments of Wells and Berkner at Huancayo, they now are statements of data as well.[8] Figure 14 exhibits a small selection from the data.

Now look again at figure 4; formerly I asked the reader to ignore one of the curves, but now we will compare the two. The circles and the crosses indicate the o wave and the x wave, respectively. One is a fairly close copy of the other, shifted a certain distance along the horizontal axis. From the magnitude of the shift it is possible to compute the strength H of the earth's magnetic field; or let me rather say, it is possible to compute a numerical value which must agree with H, or else the theory will be vitiated. When the computation is made, the value turns out to be just a few per cent less than the field strength at ground level. The action of the field through the electrons on the waves is exercised only in the ionosphere, which is hundreds of kilometers up in the sky; and it is quite reasonable to believe that these few per cent are actually the falling-off in the field strength from the ground up to that level. Such is the present belief, and many of those who work in terrestrial magnetism are happy over the prospect of measuring thus the field in regions where there seems to be no greater hope of anyone ever actually going, than of going to the moon.

Actually figure 4 shows data obtained in England, which is far from the equator; I point this out in order to mention that even when the waves are traveling obliquely to the earth's magnetic field, there is a separation of the signals into pairs of echoes, and these are still amenable to theory. In this general case of oblique transmission, the waves are polarized elliptically—a feature difficult to visualize without a certain amount of specialized knowledge, but lending itself to some very neat and pretty experimental tests.[9] In the special case of transmission parallel to the magnetic field, waves initially plane-polarized should remain of this character but their plane of polarization should rotate as they proceed. There are indeed so many curious and interesting details of the influence of the field through the electrons on the waves, that a lecturer must be ruthless in ignoring them if he is to observe decent limits of time. I will mention only in closing that the "gyro-frequency" $eH/2\pi mc$—which in our latitudes (New York City) is around 1.3 megacycles—plays the part of a resonance frequency. Waves too close to this frequency are liable to great, not to say distressing, anomalies in transmission. Theoretical statements about waves in general are likely to assume two different forms, one appropriate to those of frequency higher and the other to those of frequency lower than the gyro-frequency. The statements made above as to the relative delays of o and x echoes refer to the former case, are to be reversed for the latter.

In figure 15 there appears something which, if the war had begun before its discovery, would perhaps have been called a "black-out." Being discovered however some years before the war, it was and is called a "fade-out." The apparatus was that which I mentioned previously in connection with figures 6–8; accordingly each of the pictures was traced in 15 minutes, and as soon as each was

8. This is a good place to speak of a question which may already have occurred to many readers, viz., the question why we assume the charged particles in the ionosphere to be free electrons rather than charged atoms or molecules. Were they of atomic or molecular mass, the separation of the o and x echoes would be inappreciable, and the "gyro-frequency", later to be mentioned, would be quite outside of the radio range. It is not, however, excluded that among the free electrons there may be a great multitude of charged atoms, perhaps even many times more numerous than they, though much less influential.

9. It may perhaps be regarded as obvious that the ellipse of polarization should be described in opposite senses in the northern and southern hemispheres, since in one hemisphere the magnetic lines of force are coming out of the ground, in the other they are diving in. This inference was tested by a special experiment in Australia, and the result was taken as establishing the "magneto-ionic theory," as this general theory is often called.

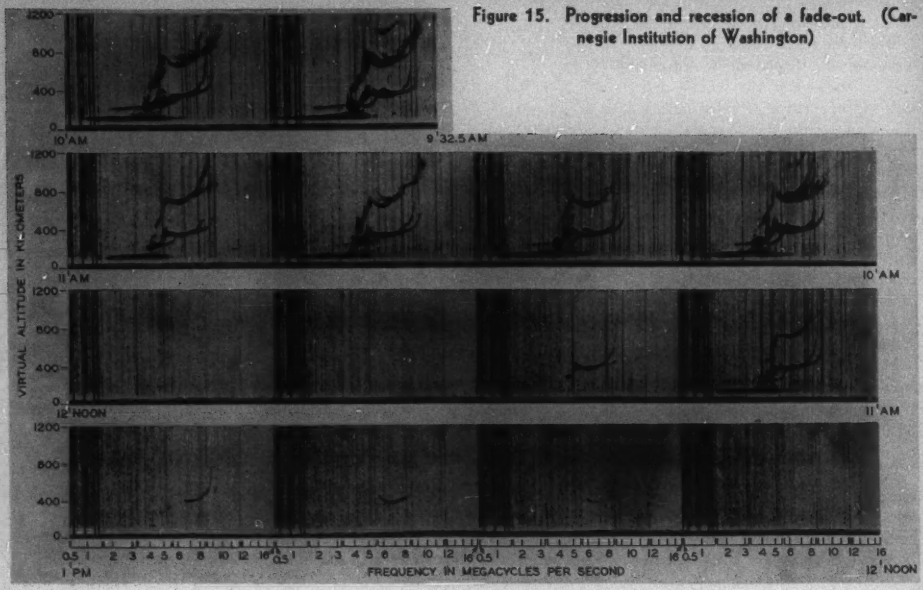


Figure 15. Progression and recession of a fade-out. (Carnegie Institution of Washington)

finished the next was begun. See how the pattern of (h', f) curves, familiar and sharp in the earlier pictures, dissolves into fragments and then is completely wiped out! Later on it begins to come back piecemeal, and finally is restored as good as ever.

Since attention was focused on such events in 1935, they have been reported by the scores in every year, varying in duration and in severity. It requires no (h', f) curve to show them, since ordinarily they cut off communication by radio, and with the sharpness of a knife. Many an engineer, to quote from Dellinger, has "dissected his receiving equipment in the vain effort to determine why it suddenly went dead." Over broad areas the extinction is sudden and simultaneous in many fade-outs, more gradual in others; and restoration is as a rule more gradual.

Shall we interpret this strange and striking effect as a sudden vanishing of the ionosphere and all the reflecting layers thereof, or as a swallowing-up of the signals by something which is suddenly created underneath the ionosphere? Against the first suggestion it is to be said that no one can imagine anything which might so suddenly frighten all the electrons of the ionosphere back under cover, so to say—drive them into the arms of their parent molecules in a few seconds or minutes—when all day and even at night they manage to hold their freedom. Such a graph as figure 16 speaks also against it forcibly. Here in the upper part of the figure we see the critical frequencies[10] of F_2, F_1 and E as located every 15 minutes on (h', f) curves such as those of figure 6. Each flock of data lies along a curve which, intercepted though it is by the fade-out, resumes so nearly at the level where it left off that one can hardly believe that the ionosphere totally vanished in between.[11]

As for the curve marked "f_{MIN}" in figure 16, it represents the lowest frequency at which echoes are observed. I have said nothing as yet about there being such a minimum-frequency. How indeed can there be one, and why should signals of any frequency however low fail to be echoed, since the mirror density for any higher frequency is *a fortiori* more than a mirror density for any lower?

Attempting to supply an answer to this question, I point out that in such part of the theory as I have thus far given, there is nothing corresponding to *absorption*. This is because the electron current (I_e in the former notation) is in quadrature with the electric vector in the waves, being thus a "wattless current." This in turn is because we have assumed each electron to be entirely free, oscillating in the wave-swept ether as though there were nothing else in the world but itself and the waves. If, however, the electron were occasionally to strike and bounce off a molecule it would leave some (even though but a small part) of its kinetic energy behind, and this would have to be replenished by the waves. Indeed as soon as collisions are taken into account, the algebra tells us that the electron current is no longer in perfect quadrature with the electric vector. Dissipation of energy occurs together with reflection, and if it is sufficiently great—if, that is to

10. For the ordinary waves, as indicated by the superscript in symbols such as f^o_2.

11. In violent magnetic storms the ionosphere is so convulsed that the echoes lose their sharpness entirely, and (h', f) curves like those of figure 7 are replaced by broad smudges; or echoes may vanish altogether. These are quite different from fade-outs.

say, the electrons collide often enough with molecules—it takes the place of reflection. In the terms of my acoustic simile on an earlier page, the signals are no longer echoed back from the hard slopes of the mountain range of figure 2*A*, but are swallowed up and lost as if in something soft and woolly.

One would expect absorption to occur in the lower reaches of the ionosphere rather than in the upper, since the air is denser there and the electrons suffer many more collisions. The absorbing layer, that is to say, must be situated just where it is able to cut us off from the reflecting layers by dissipating the signals which we send. Why should it do so occasionally with such completeness, and most of the time not do so at all, for any except the lowest frequencies?

For an answer to this query, one looks again to the sun. Ordinarily, we will suppose, the ionizing agent coming

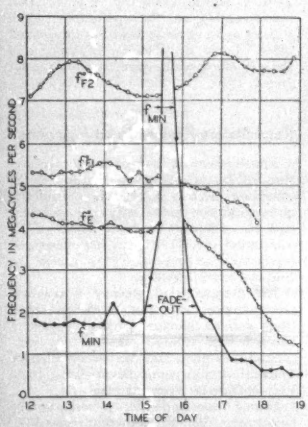


Figure 16. Trend of the critical frequencies and of the minimum echoed frequency as a fade-out proceeds (Berkner)

from the sun penetrates deep enough into the air to form the reflecting layers high overhead, but is nearly consumed in so doing. Occasionally though the sun sends forth a quite abnormal transitory burst of radiation, so strangely constituted that it passes the reflecting layers without contributing to them or weakening itself, and continues so far down that at the level where it at last engenders free electrons they constitute a layer absorptive and not reflective. This would be no more than an *ad hoc* assumption, were it not that brilliant eruptions are frequently seen on the face of the sun at the moments when fade-outs are commencing. To some extent it is still an *ad hoc* assumption, for the light whereby the eruption is seen is certainly not ionizing light, and we must assume that the visible light is attended by rays of other wave lengths having just the properties desired. Coincidence of fade-out and eruption is, however, so frequent, that it would now take a very skeptical mind to reject the assumption. The trend of the curve "f_{MIN}" in figure 16 sustains it.

And so I have now come back to the theory that it is radiation from the sun which makes the upper atmosphere into an ionosphere, by detaching electrons incessantly from the molecules thereof. (The detaching must be incessant, for the electrons are always liable to recapture by the molecules.) Of this theory it may be said that the major facts confirm it, though at night the E ionization persists so tenaciously that we are obliged to seek for a separate agent (meteors, perhaps?), while numerous minor discrepancies can be explained away by making special assumptions which can neither be confirmed nor refuted because there is so little independent knowledge of the upper atmosphere—not a very satisfactory situation for the present, but at any rate one which offers endless promise!

Thus it can readily be seen that as the ionizing light descends from heaven through the upper air, the ionization per unit volume should at first increase (because the air is getting denser) and then decrease (because the light is getting to be used up). This offers an explanation for a layer; and the mathematical working out of the idea—due in the main to Chapman—shows that not only the existence but the shape of the peak in the curve of figure 2 is compatible with the theory. But there are several layers and peaks, not just one; how does this come about? Well, the atmosphere is a mixture of several gases, differently susceptible to the ionizing light; one can attribute a peak to each gas (indeed more than one to a gas, by invoking different states of the molecules). The height of a peak, the N value at the crown of a layer, should rise and fall as the sun rises and sinks in the sky. This is true of the layers E and F_1, as we saw from figure 12; and again there is a quantitative theory by Chapman, which is borne out in some though not in full detail. Of F_2 it is not always true, as figure 12 proclaims: There is a minimum at noon in summer, and the highest N values of all are attained in winter! One tries to cope with the discrepancy by assuming that as the sun climbs higher in the sky, the F_2 region expands so much in the heat that although the total number in the region is properly increasing, the number in unit volume suffers a decline. The layers do not disappear at night, though the N values shrink. There seems to be plenty of time for recapture of all the electrons between sunset and sunrise, and one is driven to hunt for other causes of ionization which emerge when the sunlight is gone.

The sunlight is therefore not the only, yet certainly the major factor in maintaining the ionosphere—not, however, any sunlight that we ever receive! This portion of the sun's outpourings is so thoroughly consumed that it never reaches down to the levels where we live. But if it did reach down, there might be no one living to report it; for it is the powerful and dangerous ultraviolet light, which when used in therapy must be used with so much care. If that of the sun were not exhausted in forming the ionosphere, it would probably be intense enough to be deadly. If the ionosphere were not formed and any being were to survive to play with wireless waves, he would find them escaping uselessly into space. So the lethal short waves of the sun are spent, not harmlessly merely but usefully, in erecting a barrier to keep the long waves of the wireless pent up within the lower atmosphere where they can be of value.

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SPEE Reports Engineering Education Progress

The record of significant trends, developments, and events in engineering education is continued in the fifth annual progress report of the Society for the Promotion of Engineering Education, released prior to its annual meeting, Berkeley, Calif., June 24–28, 1940, by Professor C. F. Scott (A'92, F'25, HM'29) chairman of the committee on 1939 progress report. The report is based upon about 60 letters from officers and chairmen of the society.

Enrolment shows an increase of nearly 30 per cent in three years. Undergraduate students in approximately 150 engineering schools in the United States and Canada today number about 106,000. Candidates for the master's degree number more than 4,700, and for the doctor's degree 850, both more than doubled in three years. The report ascribes this increase "partly to the employment situation but mainly to the growing regard for engineering training as a preparation for careers in industry, business, and public service." Greatest increase in enrolment during this period, 89 per cent, was in mechanical engineering and "may be traced to the character of this curriculum and to the recent publicity given to aeronautics, Diesel engines, and air-conditioning. Most mechanical-engineering curricula stress management and labor problems, which may be an added explanation."

Chemical engineering, the report indicates, is maturing rapidly, and becoming more and more a mathematical, quantitative kind of engineering; its technical literature is growing; the quality of instruction and the physical facilities of the schools are improving; and a younger generation of teachers is putting it across. Advances being made by engineering schools in the teaching of physics, English, aeronautics, surveying, geodesy, mathematics, hydraulics, and fluid mechanics, are also indicated.

On the subject of research, the committee quotes a statement to the effect that "prior to 1933 over half of new-process and new product development came from Central Europe; in 1938, less than five per cent. Totalitarian influence on education is forcing American industry to a new dependence on research 'made in U.S.A.' The war in Europe may have an important influence here in the transplanting of refugee scholars."

SPEE's committee on aims and scope of engineering curricula in its contribution to the report stresses the fact that the normal basic course should prepare engineers for a wide range of technical, administrative, and executive responsibilities. Some of the views it has considered are: (*a*) the lengthening of the undergraduate curriculum to five or six years, (*b*) requirement of a period of preliminary study in a school of liberal arts preceding admission to the school of engineering, and (*c*) the trend toward dividing the curriculum in the junior and senior stages.

The past year brought to completion the second stage in the accrediting program of the committee on engineering schools of the engineers' council for Professional Development of which SPEE is a member body. In the first stage, the program of inspection was organized and principles and procedures were developed, which have now been put into operation. Today an essentially complete list of accredited curricula of the engineering schools of the country is available for the guidance and use of state licensing boards for engineers, the national engineering societies, and the thousands of high-school students contemplating an engineering career. The interchange of information also has given opportunity for all schools to improve their educational programs.

Future Meetings of Other Societies

American Chemical Society. Fall meeting, September 9–13, 1940, Detroit, Mich.

American Gas Association. October 7–10, 1940, Atlantic City, N. J.

American Institute of Mining and Metallurgical Engineers. Regional meeting, September 10–13, Salt Lake City, Utah.

American Society of Civil Engineers. Annual convention, July 24–26, 1940, Denver, Colo.

American Society of Mechanical Engineers. Fall meeting, September 3–6, 1940, Spokane, Wash.

American Transit Association. 50th annual convention, September 23–26, 1940, White Sulphur Springs, W. Va.

Engineers' Council for Professional Development. Annual meeting, October 24, 1940, Pittsburgh, Pa.

Illuminating Engineering Society. 34th annual convention, September 9–12, 1940, Spring Lake, N. J.

National Safety Council. October 7–11, 1940, Chicago, Ill.

Employment Service Incorporates, Opens New Regional Office

The employment service maintained jointly by the four founder engineering societies has been incorporated in New York State and its name changed to Engineering Societies Personnel Service, Inc. The move was made to satisfy legal requirements in some of the states in which the service operates. Officers of the corporation are: George T. Seabury, president; C. E. Davies, vice-president; O. E. Hovey, treasurer; A. H. Meyer, secretary. The present staff will continue with the corporation.

To meet the increased demand for engineers, the Engineering Societies Personnel Service, Inc., has been requested to open a fourth regional office in Detroit, Mich., in addition to those already operating in New York, N. Y., Chicago, Ill., and San Francisco, Calif. A survey of the situation and preliminary arrangements were made by a special committee, representing the founder societies and the Engineering Society of Detroit. R. E. Greene (A'26), Detroit Edison Company, is the AIEE representative on the committee, which will act as an advisory board to the Detroit office. Louis E. Williams is manager of the new office, which expects to open about July 1, 1940.

Resuscitation Review Board Appointed

Appointment of a board whose objective will be to make further study of the effects of electric shock, the possibilities of resuscitation under varying conditions, and the comparative effectiveness of resuscitation procedure has been announced by the accident prevention committee of the Edison Electric Institute.

The Resuscitation Review Board will receive reports on cases of electric shock from various sources, particularly members of EEI technical committees, electrical associations, and the National Safety Council. Utility companies are being urged to co-operate by reporting cases.

Among those appointed to serve on the board are: W. B. Kouwenhoven (A'06, F'34), dean of engineering, Johns Hopkins University, Baltimore, Md.; E. W. Oesterreich (A'21, M'25) general superintendent of distribution, Duquesne Light Company, Pittsburgh, Pa.; Wills Maclachlan (A'08, F'21) consulting engineer, Toronto, Can.; A. B. Campbell (A'20, F'38) engineer, EEI, New York, N. Y., and secretary, accident prevention committee; W. R. Smith (M'13, F'30) safety engineer, Public Service Electric and Gas Company, Newark, N. J., and chairman, accident prevention committee.

Heating and Ventilating Guide for 1940. Enlarged in scope, but "streamlined" and reduced conveniently in bulk, is the new (18th) edition of the American Society of Heating and Ventilating Engineers' "Heating, Ventilating, and Air Conditioning Guide for 1940." Consistent with its policy, the society still is effectively following and helpfully reflecting the increasing wealth of experience and technical data in a rapidly and constantly expanding field. The physical bulk of the new volume has been reduced in part by elimination of repetition of material, by some consolidation in material, and by

the use of thinner paper. As usual, the volume contains three sections: technical data, catalog data, and society roster. The volume is 6 by 9 inches in size, 1⅞ inches thick, and contains a grand total of 1,207 pages. It is available at $5.00 per volume from the ASHVE, 50 Madison Avenue, New York, N. Y.

Industrial Control Standards. The National Electrical Manufacturers Association has recently issued its "Industrial Control Standards", a compilation of information on the manufacture, test, and performance of industrial control equipment that represents standard practice in the United States. Copies of the publication, which contains 77 pages, may be obtained at $1.00 each from NEMA, 155 East 44th Street, New York, N. Y.

From AEC • •

ITEMS appearing under this heading are from the news service of American Engineering Council.

FCC Acts on Television and Frequency Modulation

After several weeks of deliberation the Federal Communications Commission has decided, for the time being at least, to stand by its contested action in refusing to permit television programs on a commercial basis pending further progress in the art. It indicated its willingness, however, to permit the further expansion of experimental television broadcasting in order that different systems now competing may demonstrate their advantages under comparable conditions. Experimental stations are now operating in New York City and Los Angeles, and applications are pending for new stations in New York City, Albany, Boston, Washington, Cincinnati, Los Angeles, and San Francisco. The Commission indicated its intention to act immediately upon these, and its readiness to entertain new applications from responsible experimenters to the extent of the limited number of wave-bands available.

In making its decision the Commission found that the major part of the industry now takes the view that a premature "freezing" of standards would hamper technical research leading to greater efficiency. As soon as the industry itself can agree upon any one of a number of competing standards, "the Commission will consider the authorization of full commercialization."

In the audible broadcasting field, the Commission acted to set aside 40 channels for both commercial and educational broadcasting by the frequency-modulation system, which it characterized as "one of the most significant contributions to radio in recent years", and which is "ready to move forward on a broad scale and on a full commercial basis." The new system requires a different type of broadcasting and receiving equipment, but because its range is now limited to an effective distance of from 40 to 60 miles is expected to find its principal field of usefulness in urban areas.

Consideration of these two problems has delayed the general shift in the assigned wave lengths of existing stations to reduce interference, which was scheduled to take place this summer, but will now be deferred until late in 1940.

United States Rushes $5,000,000,000 Defense Program

Germany's startling successes with her new kind of mechanized warfare during the past month have awakened the United States to one of its periodic realizations that its defenses are entirely inadequate, with the result that rush legislation is currently being passed to provide nearly $5,000,000,000 to expand the personnel, equipment, and facilities of the Army and Navy, and the civil production facilities necessary to accomplish this task.

In justice to the present Administration the fact should be pointed out that it has been as liberal with the defense establishment as was consonant with public opinion, even to the point of incurring considerable criticism for the extent to which it has allocated emergency expenditures for military purposes. Responsibility for the present inadequacy must be laid, not to any group or class, but to public sentiment as a whole. In this neglect the United States is not alone, as is evidenced by the succession of European nations that have found themselves virtually helpless in the face of new methods of mechanized warfare, even though most of them were better prepared than is the United States at this time.

No one can state with authority, of course, that the totalitarian powers will be victorious over Great Britain and France or that, in such an event, they will attack this country. But events of the past few months have repeatedly demonstrated the fact that the desire to remain neutral is no insurance against invasion, and it is the essential business of any nation to prepare itself to meet possible contingencies, even though they may be considered remote.

The current preparedness drive was initiated by a message to Congress delivered personally by President Roosevelt on May 16, in which he asked for the immediate appropriation of $896,000,000, in addition to contract authorizations to be met from later appropriations of $286,000,000, for the expansion of the Army, Navy, and Marine Corps. As reports from Europe became more and more serious these amounts were subsequently stepped up until they reached a total of $4,672,011,352, with no assurance that the end is in sight. This is equivalent to three-quarters of the amount spent for military purposes by this country during the first fiscal year of the World War.

The complexities and ramifications of the proposed program are too complex to be presented here in detail. Among the more significant items are the procurement of full equipment for an army of 1,000,000 men, as compared with a present strength of 230,000; major increases in the number of vessels and personnel of the Navy, and expansion of the air forces. In addition, it is desired to step up facilities for aircraft manufacture to a potential capacity of 50,000 planes per year, as compared with present estimates of 12,000, and to train large numbers of pilots and mechanics. Included in the Army equipment orders will be large quantities of mechanized units, including tanks, trucks, antiaircraft and antitank guns, fire-control equipment, and similar material. Also planned are many new air bases, training stations, and other facilities to care for the increases in personnel and equipment.

To finance these large expenditures Congress has under consideration measures to expand the present debt limit of the government and to increase taxes. Details are still unsettled, but it appears probable that income-tax rates will be increased to the order of ten per cent, income-tax exemptions may be lowered, and excise taxes on many items, such as liquor, tobacco, gasoline, and other commodities, may be increased.

ECONOMIC EFFECTS

A program on so large a scale, requiring the adjustment of private industry to many entirely new products, is sure to have innumerable repercussions. In some lines of industry these will be minor, while in others large problems will arise. Perhaps the three fields most directly affected are the aviation, shipbuilding, and machine-tool industries, already strained to capacity and now facing the need to step up production even more. All three face the immediate necessity of greatly expanding plant capacity and personnel.

Steps already taken in the aviation industry serve to illustrate the complexity of the problems involved. Already hard at work on rush orders for military aircraft for foreign buyers, this group faces the necessity of quickly expanding its rate of production from the present level of 12,000 planes per year to a new goal of 50,000. Leaders of the industry have already been called to Washington to discuss ways and means.

Such new plants as are necessary will be built, with the Government evidencing a strong desire to have them located between the Allegheny and Rocky Mountains, so as to be protected from attack. Government aid in financing expansion will be made available, either through the Reconstruction Finance Corporation or otherwise. In order to make the most effective use of existing plants, steps have already been initiated to pool American patents and to acquire those held abroad—the Government, for example, has received a license to manufacture the Rolls Royce 12-cylinder liquid-cooled motor used in Britain's fastest ships.

Studies are under way leading to the standardization of orders in a few selected types of planes, each of which will be manufactured in a number of factories. The same procedure will be followed in stepping up airplane-motor production, currently the "bottle-neck" in military plane output. A committee has been formed to study available types and select those that will be adopted.

Consideration is being given to converting some of the surplus automobile-manufacturing capacity to airplane motors. A shortage of tool- and die-makers is anticipated and if it develops the auto manufacturers may be asked to forego their usual annual practice of announcing new models for 1942 (1941 model changes are already well ad-

vanced and will not be interfered with). Glenn L. Martin estimates that it now requires from 350 to 400 man-hours to produce a small plane, and the amazing total of 14,000 man-hours to turn out a large bomber, as compared with 218 hours for the standard low-priced motor car. Studies are being made to adopt more mass-production methods and cut down this labor requirement.

DEFENSE BOARD APPOINTED

The number and magnitude of the problems that must be solved to render the defense program a reality prompted President Roosevelt on May 28 to create a commission of seven members to plan and coordinate the efforts of the many participants who must take part in this effort. The members, and their respective responsibilities, are:

Edward R. Stettinius, Jr., who resigned as chairman of the board of the United States Steel Corporation to supervise the orderly production and delivery of needed raw materials.

William S. Knudsen, given a leave of absence from his position as president of General Motors to direct industrial manufacture.

Sidney Hillman, president of the Amalgamated Clothing Workers Union, placed in charge of personnel problems, including the training of additional workers.

Chester C. Davis, member of the Federal Reserve Board, to take care of problems relating to agriculture.

Ralph Budd, chairman of the Chicago, Burlington and Quincy Railroad, to co-ordinate transportation and secure prompt delivery of raw materials and finished goods.

Leon Henderson, member of the Securities and Exchange Commission, to keep a check on industrial price trends, particularly as regards raw materials.

Miss Harriet Elliott, dean of women, University of North Carolina, to protect consumers.

While no specific authority was granted to this board to enforce its decisions and policies, the President is clearly determined to give it any necessary backing in preventing the defense program from becoming a mad scramble and causing unnecessary economic disruptions.

EFFECTS ON LABOR

Statements of the CIO, the AF of L, and the Bureau of Labor Statistics agree on the conclusion that an adequate supply of skilled labor is available, although some shortages will undoubtedly occur in specific localities. The United States Employment Office is already taking steps to transfer workers from points where there is a surplus to meet such conditions.

Many government officials, however, anticipate shortages in certain trades and a plan has been proposed for training courses to enroll a million young men from the NYA, CCC, and civilian life for noncombatant service. The Civil Aeronautics Authority is proceeding with a program to start July 1 for the enrollment of 50,000 young men in primary flying courses, as well as several thousands of others with aviation experience to take advanced courses. Because of the high standards of military aviation, it is estimated that only ten per cent of these will become suitable for combat flying. To maintain a fleet of 50,000 planes is estimated to require from 100,000 to 150,000 expert pilots, in addition to 500,000 ground personnel, the majority of whom must be highly trained technicians. The Army now has only 3,700 active and 2,000 reserve pilots; the Navy, while not announcing the number of its pilots, has a total air personnel of less than 5,000. The Navy's shipbuilding program alone will give employment to 50,000 men in addition to those currently working in yards. Altogether, it is clear that many new and expanded avenues for employment will be opened up by the preparedness program.

OTHER ANGLES OF THE PROGRAM

Among the many new developments springing from this sudden activity may be mentioned the decision of the Civil Service Commission to go on a 24-hour basis in order to meet promptly the calls for additional personnel; the reversal by the House of Representatives of its previous decision to postpone the construction of a third set of locks for the Panama Canal; the announcement by the Federal Works Agency that its personnel records of furloughed engineers will be made available to private employers needing such help to speed up production; and the transmission by President Roosevelt of Reorganization Plan V, transferring the Immigration Service from the Department of Labor to the Department of Justice.

Industry • • • •

Photoelectric Phonograph

Reproduction of sound from records through the use of the photoelectric cell has been accomplished in a new phonograph developed by the Philco Corporation and recently demonstrated at Chicago, Ill. Constituting the first basic change in the principles of phonographic reproduction since Edison's original invention, the new process is declared by the company to provide notable improvement in tone quality and range of reproduction and a tremendous extension of the life of records.

In the new phonograph, the needle, whose forced vibrations reproduce the variations recorded in the grooves of the revolving record, has been replaced by a sapphire jewel that floats through the grooves, transmitting the tone vibrations to a tiny mirror swinging freely on an axis. A beam of light produced by a small bulb and directed at the mirror picks up the vibrations and reflects them on a photoelectric cell, which converts them into electric currents to be amplified and reproduced as sound. The floating jewel thus acts merely as a control valve to operate the photoelectric cell. A steady flow of light for the bulb is provided by an oscillator by which 60-cycle alternating current is transformed into high-frequency current of 1,800,000 cycles. The bulb, specially designed, is filled with argon.

Replacing the needle with a floating jewel virtually eliminates wear on records, greatly increasing their life. The jewel is stated to have a life of eight to ten years.

A. E. Morgan, former chairman and chief engineer of the Tennessee Valley Authority, has returned to the presidency of the Dayton-Morgan Engineering Company, from which position he resigned in 1933 to go with the TVA. The company has recently been reorganized and has moved its offices from Dayton to Yellow Springs, Ohio.

Letters to the Editor • • •

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers; publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy as inked drawing without lettering, the other lettered. Captions should be supplied for all illustrations.

A Modern Aspect of Engineering Education

To the Editor:

The problem cited in the article on page 119 in the March issue of ELECTRICAL ENGINEERING, has been of major interest to business executives, educational authorities, and the students themselves, for many years past, as well as a theme of considerable anxiety and thought for parents.

One of the points that seems to confuse the minds of the younger generation, both students and graduates, is the uncertainty of objectives; they seem not to know where to look for authoritative guidance.

In your issue of reference, Doctor Torchio on page 101 deprecated the decision of the United States utilities to adhere to Edison's original voltage, nominally 110, and mentions the advantages of a nominal voltage of 220, such as is currently used in Europe and countries subject to Continental influence.

In the *Journal* of The Institution of Electrical Engineers, London, January 1940, page 25, an English engineer states that he regrets the English necessity for adhering to standards of a nominal 220 volts, and details with considerable emphasis the disadvantages thereof.

On page 62 of the same issue another engineer mentions the growing need in England of high tension transformer supply paralleling the low tension mains. This latter practice closely parallels the United States practice of installing small transformers at long intervals for light load areas and decreasing the transformer spacing as the load grows.

Having maintained a large number of contacts with engineers in the United States and abroad, I have found this general matter of voltage the subject of many acrimonious discussions with my friends and acquaintances. From them I have gathered that there seems to be little doubt that a 220/380 volt installation is cheaper

in the beginning, but because of the smaller conductors used is likely to be flimsy. At any rate, and in spite of many efforts, I have not been able to ascertain with any degree of exactitude comparable costs based on area, distance, and load.

In any case, outside of certain areas in Canada, Switzerland, and Scandinavia, where especially favorable rate conditions prevail, the voltage standards used in the United States have caused or permitted more widespread use and a greater degree of convenience and safety than I have observed anywhere else in my rather extensive travels.

What I have in mind is that perhaps the Edison Electric Institute or the National Electrical Manufacturers' Association, or the Federal Government can compile a list of nationally recognized needs that could form the subject of concrete study and effort. I simply picked up this glaring difference of opinion because it was handy, but to anyone reading the current technical press, many such examples become evident every month.

Best regards from Chile.

A. J. NOERAGER (A'11)

(Chief Electrical Engineer, Braden Copper Company, Rancagua, Chile)

"Reciprocal Addition"

To the Editor:

Mr. Blade's letter on "Reciprocal Addition" (*EE, June '40, p. 246*) is interesting from a mathematical point of view. But when the parallel resistors or the series capacitors are of values that do not lend themselves to easy calculation for least common denominators or numerators, both the conductance and the "reciprocal addition" method are cumbersome.

Why not dispense with fractions altogether? Use decimals. The use of the reciprocal scale on the slide rule will make these calculations extremely simple.

Take five parallel resistor elements of, say, 3. 4, 7, 11, and 13 ohms. The equivalent resistance

$$R = \frac{1}{\frac{1}{3}+\frac{1}{4}+\frac{1}{7}+\frac{1}{11}+\frac{1}{13}}$$

or

$$R = \text{recip}(\text{recip } 3 + \text{recip } 4 + \text{recip } 7 + \text{recip } 11 + \text{recip } 13)$$

$$R = \text{recip}(0.333 + 0.250 + 0.143 + 0.091 + 0.077) = \text{recip } 0.894$$

$$R = 1.12 \text{ ohms}$$

SANFORD HERSHFIELD (Enrolled Student)

(Cooper Union Institute of Technology, New York, N. Y.)

Federal Water Power and Electrochemical Industries

To the Editor:

I read with a great deal of interest Doctor Fink's article in the February 1940 issue of ELECTRICAL ENGINEERING. It certainly indicated a bright future for the electrochemical industries.

However, my sense of engineering justice based on the supreme law of the conservation of energy urged me to draw attention to Doctor Fink's statement concerning the huge power development possibilities at Victoria Falls in Rhodesia, Africa. He quoted the volume of water as "20 to 60 million gallons daily" (presumably imperial gallons). According to all information that I have been able to locate, the height of these falls is approximately 400 feet.

The application of a little mathematics, using the maximum total flow, gives a figure of 3,770 kw possible.

Therefore from Doctor Fink's own figures, I would conclude that the 4,000-kw installation now in operation (presumably) at Victoria Falls, has not only "scratched the surface" but made a lasting impression upon it.

R. F. CLINE (A'37)

(Norton Abrasives, Chippawa, Ontario, Canada)

Editor's Note: Because various consular offices and information bureaus could not supply information regarding the flow of the Zambesi River over Victoria Falls, and because reference to encyclopedias and other supposedly authoritative published material yielded widely varying figures, a request for information was addressed to the director of publicity at Salisbury, Southern Rhodesia; his reply follows:

To the Editor:

I have to acknowledge with thanks receipt of your letter of 14th March 1940. In regard to your questions, the following information will be of use to you.

Highest maximum flow of water over Falls (April 1934)	165,000,000 gallons per minute
Mean maximum flow of water over Falls, flood season	120,000,000 gallons per minute
Lowest minimum flow of water over Falls (October 1924)	6,500,000 gallons per minute
Mean annual flow of water over Falls	47,000,000 gallons per minute
Average height of Falls	352 feet

I am afraid I cannot tell you anything about the estimated horsepower that could be developed at the Victoria Falls if all the water was to be used for power purposes, but no doubt you will be able to work that out for yourself from the data given.

E. C. ALDERSON

(Director of Publicity, Salisbury, Southern Rhodesia)

Books Received

"Playing With Lightning." This new book by Karl B. McEachron (F'37) and Kenneth G. Patrick is a biography of lightning with technical terms held down to a minimum, yet with scientific accuracy. The study of lightning is traced from early observations to the present-day artificial-lightning generators in laboratories, and photographic and electrical equipment for "fingerprinting" natural lightning. Chapters are devoted to some case histories to illustrate unusual pranks played by lightning, to a discussion of the value of lightning rods, and to answers to some of the most popular questions regarding lightning, such as "Where is the safest place in the home during a storm?" The book contains more than 200 pages, with 16 illustrations, and is published by Random House, New York, N. Y.; the price is $2.50.

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

ENGINEERING REORGANIZATION. By J. J. Gillespie, with a foreword by D. Brown. Pitman Publishing Corporation, New York, 1940. 268 pages, illustrated, 8½ by 5½ inches, cloth, $4.00. For engineering companies not engaged on continuous or mass production. Planning, material and quality control, time study and job analysis, costing and sales methods are discussed, with specific examples and applications.

FUNDAMENTAL PRINCIPLES OF ELECTRIC AND MAGNETIC CIRCUITS. By F. A. Fish. Third Edition. McGraw-Hill Book Company, New York and London, 1940. 229 pages, diagrams, etc., 9½ by 6 inches, cloth, $3.00. Intended for undergraduates as an introduction to the study of electric-power machinery and transmission. This edition partly rewritten; some new material.

MODERN ELECTRIC AND GAS REFRIGERATION. By A. D. Althouse and C. H. Turnquist. Third revised and enlarged edition. Goodheart-Willcox Company, Chicago, 1939. 858 pages, illustrated, 8 by 5 inches, leather, $5.00. For school and home use, covers both domestic and commercial refrigeration. Fundamental physical principles, installation, servicing, refrigerants, and air conditioning are treated. Domestic refrigerator specifications are given. Review questions with answers.

EINFÜHRUNG IN DIE THEORETISCHE ELEKTROTECHNIK. By K. Küpfmüller. Second enlarged edition. Julius Springer, Berlin, 1939. 343 pages, diagrams, etc., 10 by 6½ inches, cloth, 19.80 rm. Introduction to the theory of electrical engineering, intended to fill a place between elementary texts and treatises upon specific applications. Includes essential physical laws and the facts and methods which the electrical engineer requires as a general background.

THE PHILOSOPHY OF PHYSICAL SCIENCE (Tarner Lectures 1938). By Sir A. Eddington. The University Press, Cambridge, England; The Macmilan Company, New York, 1939. 230 pages, 9 by 6 inches, cloth, $2.50. Examines the nature of physical knowledge and demonstrates its application to the physical universe. The two final chapters present an outline of a general philosophical outlook which the author believes a scientist can accept without inconsistency.

A PRIMER OF TIME STUDY. By F. W. Shumard. McGraw-Hill Book Company, New York and London, 1940. 519 pages, illustrated, 9 by 6 inches, cloth, $5.00. Based on the use of the stop watch as a means of establishing standard time and energy values for machines and men. Piecework premium, and group-incentive plans are treated. Examples and test questions.

AMERICAN PLANNING AND CIVIC ANNUAL. Edited by H. James. American Planning and Civic Association, Washington, D. C., 1939. 288 pages, illustrated, 9 by 6 inches, cloth, $3.00. The papers included in this volume have been presented at various national and regional conferences, and are grouped under the headings of community reclamation, industrial migration, man-made obstacles to planning, rural problems, national income, public works, state and national parks. They constitute a survey of current work.

ELECTRODYNAMICS. By L. Page and N. I. Adams. D. Van Nostrand Company, New York, 1940. 500 pages, diagrams, etc., 9½ by 6 inches, cloth, $6.50. Advanced treatment of the theoretical aspects of electrodynamics, covering the electromagnetic field, energy, stress, momentum, wave motion, radiation, three-dimensional and four-dimensional vector analysis, and the principle of relativity.

THE STORY OF THE LAMP AND THE CANDLE. By F. W. Robins. Oxford University Press, London, New York, and Toronto, 1939. 155 pages, illustrated, 10 by 7½ inches, cloth, $5.00. The history of lighting methods from the earliest times to the advent of electricity. Deals fully with the torch, candle, and various types of lamps, but touches only briefly upon gas lighting.

Institute Activities

Pacific Coast Convention Will Combine Technical and Recreational Features

A PROGRAM of technical sessions including a special student session, varied inspection trips, social and sports events, has been arranged for the 1940 Pacific Coast convention, to be held at Los Angeles, Calif., August 27–30. As convention headquarters, the Ambassador Hotel has many advantages. Conveniently near the Los Angeles shopping district, it has 22 acres of grounds, with excellent outdoor swimming pool, pitch and putt golf course, tennis courts, and other facilities including its widely known Cocoanut Grove.

VACATION OPPORTUNITIES

Southern California is famous for its numerous vacation spots. Its proximity to the mountains and sea offers vacation possibilities to satisfy the most exacting. Among varied points of interest in and around Los Angeles are: Huntington Art Galleries and Gardens, San Juan Capistrano and other missions, Palomar Mountain, where the 200-inch telescope is located, California Institute of Technology, where the 200-inch mirror is being prepared, Gay's Lion Farm (200 lions), and others. Those attending the convention should not lose sight of the opportunity of visiting the Golden Gate International Exposition at San Francisco either before or after the meeting.

Members proposing to attend the convention, who would like advice on planning vacation schedules, may obtain full information by writing to O. W. Holden, chairman of the inspection trips committee, at 207 South Broadway, Los Angeles, Calif.

Schedule of Events

Tuesday, August 27

9:00 a.m.	Registration
10:00 a.m.	Opening of convention and address of welcome by N. B. Hinson, convention chairman
10:15 a.m.	Address by President-Elect Sorensen
10:45 a.m.	Address by Douglas Shearer
2:00 p.m.	Session on protective devices
5:30 p.m.	President's informal reception
7:00 p.m.	Student-counselor dinner and conference
7:30 p.m.	Trip to Planetarium

Wednesday, August 28

9:00 a.m.	Session on power transmission and distribution
9:00 a.m.	Conference on governors, frequency control, and load swings
2:00 p.m.	Session on electrical machinery
2:00 p.m.	Session on instruments, measurements, and basic sciences
2:00 p.m.	Student technical session
9:00 p.m.	Dinner, dancing, Cocoanut Grove

Thursday, August 29

9:00 a.m.	Communications session, joint with Institute of Radio Engineers
2:00 p.m.	Golf tournament at the Riviera Country Club
2:00 p.m.	Student technical session
7:00 p.m.	Buffet dinner, dance, and presentation of sports prizes, Riviera Country Club

Friday, August 30

Inspection trips: trips to points of interest in and around Los Angeles

TECHNICAL SESSIONS

The opening session of the convention will be addressed by President-Elect R. W. Sorensen on the subject "Science and Superstition." An address will be presented by Douglas Shearer, sound director of Metro-Goldwyn-Mayer Studios, whose talk is expected to be of great interest.

Five technical sessions and one technical conference are tentatively scheduled. Four of the five technical sessions will consist of papers and discussions, and the fifth will be a joint meeting with the Institute of Radio Engineers who are holding their convention at the same time. A nationally known speaker will be present to address this session.

The technical conference, one of the high lights of the technical program, will deal with the subject of governors, frequency control, and load swings, with several leading engineers entering into the discussion.

The technical program is scheduled to be published in the August issue.

STUDENT ACTIVITIES

The student counselor dinner and joint conference on student activities will be held on Tuesday evening, the opening day of the convention. All student delegates and counselors as well as others interested are urged to attend.

Holding the student technical sessions on Wednesday and Thursday afternoons will enable students and others interested to take part in these discussions without missing many other important sessions of the convention. Students are invited to attend all the convention activities, including the technical sessions, entertainment, and inspection trips.

Among the papers to be presented by students are the following:

MEASUREMENT OF REACTIVE VOLT-AMPERES BY MEANS OF SYMMETRICAL COMPONENTS, **Charles B. Lee**, University of Washington

STABILIZED NEON-TUBE COUPLED AMPLIFIER, **W. H. Huggins**, Oregon State University

TWO-MILLION-VOLT IMPULSE GENERATOR, **W. R. Johnson**, Stanford University

IMPROVED-TYPE LOSSER MODULATOR, **V. S. Carson**, Stanford University

ONE-METER REPLICA GRATING SPECTROGRAPH, **J. Mitch**, Montana State University

PERMEANCE OF TAPERED SLOTS IN ELECTRICAL MACHINES, **T. C. Wang**, California Institute of Technology

ENTERTAINMENT

There should be no dull moments for anyone attending this convention since plenty of entertainment will be offered. An informal reception on Tuesday afternoon provides an opportunity for members to make and renew acquaintances. Following this reception a trip has been arranged to the Griffith Park Planetarium, the only one west of the Mississippi. A lecture will be presented by the planetarium astronomer on the subject "Comets and Meteors," which should be most entertaining and instructive.

On Wednesday evening a dinner will be held in the nationally famous Cocoanut Grove, special arrangements having been made for the convention attendance. A section of the Grove will be reserved and those attending will be able to enjoy the regular floor show and dancing.

After the golf tournament on Thursday a "Noche de Fiesta" will be celebrated at the Riviera Country Club. At this informal gathering, a buffet dinner will be served, followed by presentation of sports prizes and dancing.

WOMEN'S ENTERTAINMENT

In addition to the entertainment already mentioned, special events have been arranged for women attending the convention: On Tuesday morning a window-shopping tour of Hollywood and Los Angeles stores may be taken, and in the afternoon a contest will be held on the Ambassador Hotel pitch and putt course. On Wednesday morning a trip is planned through Hollywood, Westwood, and Beverly Hills, where many of the homes of motion-picture celebrities can be seen. This trip will continue to the beaches with lunch arranged en route. On Thursday women guests will be taken to the Riviera Country Club and Deauville Club where swimming, golf, and putting are available. A dessert-bridge has also been arranged, starting at 1:00 p.m.

A reception committee will be at the registration desk to assist women guests to plan their time during the convention. Every assistance will be given to insure that they enjoy themselves in the way they most desire.

SPORTS

Thursday afternoon has been set aside for the annual golf tournament which will be held at the Riviera Country Club. This course is noted for its excellence, beauty,

and its magnificent location in the Santa Monica hills close to the ocean. Those not wishing to play golf may spend the afternoon watching a polo game or at the near-by Deauville Beach Club, the full facilities of which will be available to members.

The main golf event will be the 18-hole handicap play for the John B. Fisken cup; this is limited to AIEE members. Additional prizes, available to both members and nonmember guests, will be given for events such as "Blind Bogey," "Lucky 3 Handicap," etc. The committee urges all members and guests, whether skilled in the ancient game or not, to plan on this afternoon of golf.

During the convention tennis matches will be arranged on the courts of the Ambassador Hotel. Other facilities of the hotel, such as the swimming pool and the pitch and putt course, will be regularly available.

INSPECTION TRIPS

Southern California points of interest selected for inspection trips include the Columbia Steel Plant at Torrance, KNX broadcasting transmitter, ship-to-shore radio station of the Southern California Telephone Company, new receiving station *E* of the AIEE or the immediate families of members.

The past two conventions in the Los Angeles area have been outside the city limits. This time the Pacific Coast convention is to be at the Ambassador Hotel, which offers excellent convention facilities in a 22-acre playground within the city.

Detailed rates at the Ambassador Hotel are:

$4.00 per day per person, two in a room with bath and individual beds

$6.00 per day one person, in a room with bath

$3.50 per day per person, with four in two connecting rooms with bath and individual beds

$3.25 per day per person, with three in a room with bath and individual beds

Rates of hotels in the vicinity of the Ambassador are given in the accompanying tabulation. Members should make their hotel reservations by writing directly to the hotel of their preference.

COMMITTEES

The personnel of the 1940 Pacific Coast convention committee is as follows:

N. B. Hinson, *chairman;* M. A. Sawyer, *assistant to the chairman;* H. L. Caldwell, *vice-chairman;* J. M. Gaylord, *secretary;* F. C. Lindvall, *treasurer. Sub-committee chairmen:* J. H. Vivian, *technical program;* J. O. Binney, *registration;* W. W. LaBarr, *finance;* T. M. Blakeslee, *hotel;* H. S. Warren, *entertainment;* Mrs. R. W. Sorensen, *women;* B. L. Bettannier, *transportation;* O. W. Holden, *inspection trips;* O. A. Gustafson, *sports;* F. W. Maxstadt, *students;* A. P. Hill, *publicity. Members-at-large:* C. A. Andrews, J. W. Barker, C. F. Bowman, Neal Baden, E. F. Ewenson, L. R. Gamble, Fred Garrison, David Hall, R. H. Halpenny, G. K. Haspel, C. J. Hawkes, H. W. Hitchcock, J. P. Jollyman, J. E. McDonald, Corbett McLean, E. R. Northmore, E. F. Scattergood, R. W. Sorensen, and F. E. Young, Jr.

Hotels and Rates

Hotel	Address	City Blocks From Headquarters	Single Room With Bath	Double Room With Bath
Ambassador	Wilshire Boulevard	Headquarters	$6.00	$6.50–8.00
Chapman Park	615 South Alexandria Avenue	One	$3.50	$5.00
Chancellor	3191 West Seventh Street	One	$2.50–3.50	$3.50–5.00
Gaylord	3355 Wilshire Boulevard	One	$4.00	$6.00 up
Langham	715 West Normandie Avenue	One-half	$3.00	$5.00–7.00
Mayan	3049 West Eighth Street	Three	$2.50	$5.00–9.00

Bureau of Power and Light, and the laboratories of the California Institute of Technology. If conditions permit, a visit to an aircraft factory may be included, although this of course will depend on national defense requirements at the time. Arrangements have been made for those who desire to see the 200-inch telescope at Mount Palomar to obtain admission. The 200-inch mirror, now undergoing final polishing at the California Institute of Technology in Pasadena, may also be seen. Trips will also be available to the Huntington Library and Art Gallery and to see the famous stained-glass window of the "Last Supper" at Forest Lawn, as well as to Chinatown and the Olvera Street Mexican Village. Additional trips to other local points of interest will be arranged on request.

REGISTRATION AND HOTELS

Members who plan to be in Los Angeles prior to the opening of the convention should indicate the fact when returning their advance registration cards, since the reception and trips committees will welcome the opportunity of meeting with them and furnishing suggestions for trips and entertainment. Registration may be completed upon arrival at the Ambassador Hotel headquarters on Monday evening, August 26, and should be definitely completed before 10:00 a.m. on Tuesday. A registration fee of $2.00 will be charged to nonmembers; no registration fee will be charged for Enrolled Students of the

National • • • •

New Officers Elected at Summer Convention

At the annual meeting of the AIEE, held during the summer convention just concluded, the committee of tellers presented its report on the election of officers for the year beginning August 1, 1940. The new officers are:

President: R. W. Sorensen, professor and head of the department of electrical engineering, California Institute of Technology, Pasadena.

Vice-Presidents: E. S. Lee, engineer in charge of general engineering laboratory, General Electric Company, Schenectady, N. Y. (District 1, North Eastern); J. W. Barker, dean of engineering, Columbia University, New York, N. Y. (District 3, New York City); K. L. Hansen, consulting engineer, Harnischfeger Corporation, Milwaukee, Wis. (District 5, Great Lakes); J. L. Hamilton, assistant vice-president, Century Electric Company, St. Louis, Mo. (District 7, South West); A. L. Taylor, dean of the school of mines and engineering and head of the electrical-engineering department, University of Utah, Salt Lake City (District 9, North West).

Directors: T. F. Barton, assistant manager of the New York district, General Electric Company, New York, N. Y.; M. S. Coover, professor and head of the department of electrical engineering, Iowa State College, Ames; R. G. Warner, engineer, United Illuminating Company, New Haven, Conn.

National Treasurer: W. I. Slichter, professor and head of the department of electrical engineering, Columbia University, New York, N. Y. (re-elected).

The board of directors for the administrative year beginning August 1, 1940, will consist of these newly elected officers and the following holdover officers:

F. M. Farmer, New York, N. Y. (*retiring president*); John C. Parker, New York, N. Y. (*junior past president*); C. T. Sinclair, Pittsburgh, Pa.; F. W. Maxwell, Jr., University, Ala.; A. L. Turner, Omaha, Nebr.; H. W. Hitchcock, Los Angeles, Calif.; J. M. Thomson, Toronto, Ont. (*vice-president*); C. R. Beardsley, New York, N. Y.; Vannevar Bush, Washington, D. C.; F. H. Lane, Chicago, Ill.; L. R. Mapes, Chicago, Ill.; H. S. Osborne, New York, N. Y.; D. C. Prince, Philadelphia, Pa.; Mark Eldredge, Memphis, Tenn.; R. E. Hellmund, East Pittsburgh, Pa.; F. J. Meyer, Oklahoma City, Okla. (*directors*).

A detailed report of the AIEE summer convention will appear in the August issue.

Institute Co-operates in Census of Engineers for National Defense

The AIEE, through its Sections, is engaged in compiling a list of firms and individual electrical engineers in private practice in the United States, as its contribution to the nation-wide census of engineers and architects being prepared by national professional organizations in the program to coordinate civilian resources for national defense. Section committees will use available sources of information to list firms and individuals in the Section territory, indicating their specialties.

Also co-operating in the national census are the American Society of Civil Engineers, American Society of Mechanical Engineers, American Institute of Mining and Metallurgical Engineers, American Institute of Chemical Engineers, American Institute of Consulting Engineers, American Society of Heating and Ventilating Engineers, American Society of Military Engineers, American Society of Refrigerating Engineers, National Society of Professional Engineers, American Institute of Architects.

The census will have three parts: first, the listing of engineering and architectural firms and individuals in private practice, now in progress; second, classification of firms and individuals according to qualifications; and third, listing and classification of engineers, architects, draftsmen, surveyors, and specialists, who may be available to work with firms on assigned jobs.

Report of the Board of Directors

THE board of directors of the American Institute of Electrical Engineers presents herewith to the membership its 56th annual report, for the fiscal year ending April 30, 1940. A general balance sheet showing the condition of the Institute's finances on April 30, 1940, together with other detailed financial statements, is included herein. This report contains a brief summary of the principal activities of the Institute during the year, more detailed information having been published from month to month in ELECTRICAL ENGINEERING.

BOARD OF DIRECTORS' MEETINGS

During the year, the board of directors held five meetings, four in New York City, and one in San Francisco, Calif. The executive committee meetings in December and March were held in place of meetings of the board. Information regarding many of the more important activities of the Institute which have been under consideration by the board of directors and the committees is published each month in the section of ELECTRICAL ENGINEERING devoted to "Institute Activities".

PRESIDENT'S AND NATIONAL SECRETARY'S VISITS

President Farmer and National Secretary Henline attended the combined summer and Pacific Coast convention, the winter convention, the Great Lakes District meeting in Minneapolis, Minn., and the Middle Eastern District meeting in Scranton, Pa. They also visited many Sections and Student Branches. During May, President Farmer will visit the following Sections: Cincinnati, Cleveland, Erie, Worcester, Niagara Frontier, and Rochester; also he will attend a conference on student activities of the North Eastern District at Troy, N. Y. Both President Farmer and National Secretary Henline will attend the summer convention in Swampscott, Mass.

The places visited by President Farmer follow:

Alabama
- Alabama Section, Birmingham
- University of Alabama Branch, University

California
- Summer and Pacific Coast convention, San Francisco

Connecticut
- Connecticut Section, New Haven

District of Columbia
- Washington Section
- American Engineering Council, Washington

Georgia
- Georgia Section, Atlanta
- Georgia School of Technology Branch, Atlanta

Illinois
- Chicago Section, executive committee
- Midwest Power Conference, Chicago

Louisiana
- New Orleans Section
- Tulane University Branch, New Orleans
- Louisiana State University Branch, Baton Rouge

Michigan
- Michigan Section, Ann Arbor

Minnesota
- Great Lakes District meeting, Minneapolis
- Conference on student activities, Great Lakes District, No. 5, Minneapolis

Mississippi
- Conference on student activities, Southern District, No. 4, State College, Miss.

New York
- New York Section
- Winter convention
- Ithaca Section
- Cornell University Branch, Ithaca
- Schenectady Section
- Syracuse Section
- Syracuse University Branch

North Carolina
- North Carolina Section, Durham

Pennsylvania
- Middle Eastern District meeting, Scranton
- Conference on student activities, Middle Eastern District, No. 2, Scranton
- Pittsburgh Section
- Philadelphia Section

Canada
- Toronto Section

The places visited by the national secretary are the following:

California
- Summer and Pacific Coast convention, San Francisco
- Conference on student activities, Pacific District, No. 8, and North West District, No. 9, San Francisco

District of Columbia
- Washington Section
- American Engineering Council, Washington

Idaho
- University of Idaho Branch, Moscow

Illinois
- Armour Institute of Technology Branch, Chicago
- Urbana Section

Indiana
- Central Indiana Section, Indianapolis
- Fort Wayne Section

Massachusetts
- Lynn Section
- Worcester Section
- North Eastern District meeting, Springfield
- Conference on student activities, North Eastern District, No. 1, Springfield

Minnesota
- Great Lakes District meeting, Minneapolis
- Conference on student activities, Great Lakes District, No. 5, Minneapolis

Montana
- Montana Section, Butte

New York
- New York Section
- Schenectady Section
- Winter convention

Ohio
- Akron Section
- Columbus Section

Pennsylvania
- Sharon Section
- Philadelphia Section
- Middle Eastern District meeting, Scranton
- Conference on student activities, Middle Eastern District, No. 2, Scranton

Rhode Island
- Providence Section

Washington
- State College of Washington Branch, Pullman
- Seattle Section
- Spokane Section

Wisconsin
- Madison Section
- Milwaukee Section

Canada
- Vancouver Section

NATIONAL CONVENTIONS

Two national conventions were held during the year, and a brief report on each follows:

Summer and Pacific Coast Convention. The 55th summer convention combined with the 27th Pacific Coast convention was held in San Francisco, California, June 26–30, 1939. In addition to the annual business meeting, and conference of officers, delegates, and members, there were nine technical sessions at which 41 papers were presented, one general session, and two informal technical conferences. Doctor Adam S. Bennion, assistant to the president of the Utah Power and Light Company, gave an address on "Human Relationships" at the general session. In addition, there were two student technical sessions with presentation of 11 papers, and a Student Branch dinner with informal addresses by President John C. Parker, Vice-President H. W. Hitchcock, and Doctor R. W. Sorensen, chairman of the committee on student branches.

Entertainment and sports features of the convention were a tea, "AIEE Day" at the Golden Gate International Exposition on Treasure Island, banquet, and golf and tennis tournaments held in competition for the Mershon, Lee, and John B. Fisken trophies. The attendance was 940.

Annual Meeting. The annual business meeting of the Institute was held on Monday morning, June 26. The annual report of the board of directors for the fiscal year which ended April 30, 1939, was presented in abstract by the national secretary. A report on the finances of the Institute was presented by National Treasurer W. I. Slichter. The report of the committee of tellers upon the election of officers for the year beginning August 1, 1939, was presented, and President-Elect Farmer responded to his introduction with a brief address. During this session, the Lamme Medal for 1938, which was awarded to Marion A. Savage, was presented, being received by P. L. Alger who represented the medalist.

Winter Convention. The 28th winter convention was held in New York City, January 22–26, 1940, with a program including 85 papers presented in 18 technical sessions and 8 technical conferences. A brief general session was held at which the Alfred Noble prize was presented to C. E. Shannon (A'39).

At an evening session, the Edison Medal was presented to Philip Torchio, and the Hoover Medal was presented to Doctor Gano Dunn.

A smoker, numerous inspection trips, and ladies' events completed the program of the convention. The registration was 1,626, which was slightly above the 1939 figure, and the highest since 1924.

DISTRICT MEETINGS

Brief reports on the three District meetings held during the year are given below:

North Eastern District Meeting. This meeting and student Branch convention was held in Springfield, Mass., May 3–5, 1939.

There were four technical sessions, two student sessions, and a general session with addresses by President John C. Parker and President C. W. Kellogg of the Edison Electric Institute, the latter on the subject "The Engineer as a Citizen". The Faraday Medal of The Institution of Electrical Engineers, Great Britain, was presented to Doctor W. D. Coolidge, director of the General Electric Company Research Laboratory, Schenectady, N. Y., by Dr. Gano Dunn, local honorary secretary of the IEE for the United States. Inspection trips, stag smoker, ladies' entertainment, and banquet completed the meeting. The attendance was 439.

Great Lakes District Meeting. This meeting was held in Minneapolis, Minn., September 27–29, with four technical sessions, at which 18 papers were presented, and one student session. The entertainment program consisted of a dinner and dance with a demonstration by Doctor Phillips Thomas, research engineer of the Westinghouse Electric and Manufacturing Company. Also Doctor W. A. O'Brien, pathologist of the University of Minnesota, addressed an audience at a noon luncheon. Inspection trips, ladies' events, a District conference on student activities, and a District executive committee meeting were included in the program. The registration was 230.

Middle Eastern District Meeting. The tenth meeting of this District was held in Scranton, Pa., October 11–13, 1939, with 5 sessions at which 21 technical papers were presented. A District conference on student activities, a District executive committee meeting, ladies' events, inspection trips, stag smoker, and informal dinner, at which President R. E. Desvernine of the Crucible Steel Company of America gave an address on "Business and World Politics", completed the program. The attendance was 313.

Table I. Section and Branch Statistics

	For Fiscal Year Ending				
	April 30, 1936	April 30, 1937	April 30, 1938	April 30, 1939	April 30, 1940
Sections					
Number of Sections	61	62	65	67	70
Number of meetings held	540	621	624	635	701
Total attendance	85,501	74,950	110,148	85,692	91,949
Branches					
Number of Branches	118	119	120	120	121
Number of meetings held	1,045	1,363	1,334	1,190	1,346
Total attendance	45,304	46,121	60,446	53,380	64,972

SECTIONS

The three new Sections organized, Charleston, El Paso, and South Carolina, brought the total number to 70. The name of the Dallas Section was changed to "North Texas", and its territory was extended to the north and northwest. On account of the fact that its territory includes the major part of the state of Maryland, the name of the Baltimore Section was changed to "Maryland". Nine unassigned counties in Maine were assigned to the Lynn Section, which now has the entire state. Organization of new Sections and extensions of the territories of others have reduced to about 100 the number of members in the United States outside Section territories.

Activity was reported by all Sections. The total number of meetings reported was 701 as compared with 635 for the preceding year, and this was the sixth consecutive year in which the number exceeded that for the preceding year.

Fifteen Sections reported that their 30 technical groups or other subdivisions had held 124 meetings of these types in addition to the 131 regular Section meetings.

In October, the Sections committee issued a printed pamphlet "Section Activities", which is expected to be of material assistance to Section officers by indicating the types of activities which have been found to be most effective. A second edition of the pamphlet "The Electrical Engineer", for the guidance of high school students interested in electrical engineering, was prepared under the joint direction of the Sections committee and the committee on Student Branches.

The Sections committee sent a communication to all Sections, in October, recommending the appointment by each of committees on (*a*) legislation, (*b*) economic and social affairs, and (*c*) vocational guidance.

Many Sections have shown increased interest in the stimulation of younger members to participate in the activities more freely. The continuing interest in and success of the technical group discussion plan, the inclusion of younger members among Section officers and committees, and the appointment of committees to develop activities for the younger engineers are a few of the tangible evidences of progress in this direction.

The Sections committee has been developing a comprehensive plan for the preparation of news items on outstanding Section activities for publication in ELECTRICAL ENGINEERING, and many such items have appeared in recent months. Through the use of extensive questionnaires the committee is making a thorough study of all phases of Section activities.

More detailed information on these activities may be found in the annual report on Section and Branch activities in the June issue of ELECTRICAL ENGINEERING, pages 250–3.

STUDENT ACTIVITIES

A new Branch organized at the University of Alberta brought the total number to 121.

The total number of meetings reported was 1,346, as compared with 1,190 for the preceding year, 1,334 for 1937–38, and 1,363 for 1936–37. Only two Branches failed to report any activity, 21 held more than 15 meetings each, 24 held from 12 to 15, 40 held from 8 to 11, 26 held from 4 to 7, and 8 held from 1 to 3 meetings.

Although the total number of student talks at Branch meetings was higher than for the preceding year, 767 as compared with 725, it was far below the numbers for some previous years. The largest number reported for any year was 1,130 for 1936–37.

The numbers of student sessions and papers at the summer-Pacific Coast convention and three District meetings are given in the reports on those meetings. The students have continued to show keen interest in such participation, and the quality of student papers and their presentation has been high.

With the co-operation of the committee on Student Branches, the committee on safety again suggested that each Branch have presented a paper on prevention of accidents or remedial measures after electric shock. A large number followed the suggestion.

A meeting of the committee on Student Branches was held during the 1940 winter convention, with 50 members and invited guests present. A report on the meeting appeared on pages 124–5 of the March issue of ELECTRICAL ENGINEERING.

The committee on Student Branches and the Sections committee co-operated in the preparation of a second edition of the pamphlet "The Electrical Engineer" for the guidance of high school students interested in electrical engineering. Distribution of copies was begun in March.

The committee on Student Branches urged the Branches to celebrate the 75th birthday of Doctor Charles F. Scott, originator of the plan for organizing Branches. The Scott motion-picture films were shown by about 75 Branches, in many cases at joint meetings with neighboring Sections or Branches.

Of the 1,624 enrolled students whose terms were expected to expire on April 30, 911 (56 per cent) applied for admission as Associates. Some are eligible to continue as enrolled students on account of remaining in school.

A more detailed summary of student activities may be found in the annual report on Section and Branch activities in the June issue of ELECTRICAL ENGINEERING, pages 250–3.

TECHNICAL PROGRAM COMMITTEE

The technical papers on convention programs have been of a high quality, with many favorable comments received. Pursuing the policy of the previous year, the technical program for the 1940 winter convention was enlarged to 18 technical sessions and 8 technical conferences, one more technical session and three more conferences than were held in the previous year. The enlarged program met with an excellent response from the membership, as evidenced by the registered attendance, 1,626, which was slightly more than the attendance of the previous year, and the largest attendance since 1924. The committee also arranged the technical program for the 1939 summer and Pacific Coast convention, and papers were supplied for the District meetings in Springfield, Mass.; Minneapolis, Minn.; and Scranton, Pa. A total of 177 papers were presented at these two national conventions and three District meetings, of which 151 were recommended for TRANSACTIONS publication.

Table II presents statistics for the pro-

Table II. Technical Programs, Last Two Years

	Year Ending April 30, 1940	Year Ending April 30, 1939
Number of national conventions	2	3
Number of District meetings	3	3
Registration at national conventions and District meetings	3,548	4,100
Number of papers presented	177	184
Number of papers recommended for TRANSACTIONS	151	169
Estimated number of pages required for printing papers in TRANSACTIONS	886*	986*
Average length of papers recommended for TRANSACTIONS	5.86	5.83
Number of technical sessions	43	50
Number of technical conferences	10	12

* Partly estimated.

gram of the past two years. These statistics are not directly comparable, as there was one less national convention during the past year due to the fact that the summer and Pacific Coast conventions were combined.

Oral Presentations. With a view toward improving the effectiveness of the oral presentations, each speaker and presiding officer at the last winter convention has been canvassed. Many helpful suggestions from a broad section of actual experience have been received. These suggestions will be carefully analyzed, mimeographed, and sent to speakers on future programs. In this way it is hoped to bring about improvement in some of the oral presentations to the mutual advantage of both the speakers and the audience.

Technical-Committee Reports. The preparation of technical-committee reports on the progress of the art has been stimulated. A report on progress of the art in electrical machinery was presented at the summer convention. Reports on progress in the production and application of light and progress in power generation, 1933–39, were presented at the winter convention. Reports by the committees on communication, protective devices, electronics, and instruments and measurements are in preparation. As most of the technical committees have not had reports since 1934, and it is planned to include developments during the intervening years, the reports will be more comprehensive than heretofore. As an experiment and for the purpose of making the reports more readable and presentable, some of the reports will be prepared by an experienced writer. Through this service, technical committee reports will receive more extensive publicity in circles outside of Institute activities.

New Trends in Policy. While the average length of papers for the fiscal year has remained practically the same as for the preceding year, 5.86 pages per paper as compared with 5.83, nevertheless the papers for the past winter convention as compared with the winter convention of the previous year were reduced from 6.50 pages per paper to 5.60. Technical committees have been requested to continue their efforts for shorter papers, which will permit the scheduling of more papers within the annual budget. Notwithstanding this reduction, when the winter convention program was determined, there still remained 51 papers on the docket which had to be held over for future meetings.

As a result of the foregoing situation, a subcommittee was appointed. It was believed that some of the more highly specialized papers of limited interest could be presented in technical conferences without TRANSACTIONS publication, and that more material could be presented in this way. The duties of the subcommittee were to study the whole problem, and a report entitled "Suggested Modifications in Methods of Handling AIEE Technical Papers and Conferences" has been made. This report was discussed at the March 15 meeting of the technical program committee, and referred back to the subcommittee for revision in the light of the discussion at that meeting.

The revised report of the subcommittee, if accepted, will divert some of the more highly specialized papers of interest to only a few and other papers which are only of transitory interest from the TRANSACTIONS to a less expensive form of publication. These papers would be permanently recorded by the publication of synopses. Preprints would be made available and the original copy filed in the Engineering Societies Library. Other unapproved conference papers would also be preserved by filing in the Library at the option of the author. The report also recommends the publication of a synopsis of every formal paper in ELECTRICAL ENGINEERING as soon as the paper has been approved for preprinting. It also recommends that some papers with longer mathematical calculations should have the appendices made available in preprint form only.

Acknowledgments. The committee is grateful for the active participation and cooperation in the work by its members, the chairmen of the technical committees, the reviewers of papers, and the members of the Institute's staff.

PUBLICATION COMMITTEE

With the transition period involved in the adoption of the present publication policy largely behind, constant attention has been given to observing residual defects and devising minor modifications to overcome them. While the general reaction of the membership continues to be very favorable, some adverse criticisms have been received and these have had and are having careful consideration.

The booklet "Preparation of Manuscripts" has been completely revised and enlarged, and is now available under the title "Information for Authors". A lack of familiarity of some authors and members with the provisions of the present publication policy has caused confusion in some cases. The new booklet "Information for Authors" contains for the first time a full statement of publication policy, and it is hoped that members and authors will take advantage of this opportunity to become thoroughly familiar with the publication policy.

During the year, a critical study has been made of AIEE publication costs, and this study included a comparison with the publication costs and procedures of three other national technical organizations. The analysis shows that in relation to the total cost to them, our members receive publication service which compares very favorably with that provided by the other organizations. The economy and efficiency of our publication procedures is indicated by the fact that last year the net publication expense per member in our Institute was only one-half of the corresponding figure in another organization having nearly the same membership.

The operating statement for the first half of the appropriation year (October 1st, 1939, to March 31st, 1940) shows that the publication committee has operated within its budget for that period.

Recently Donald M. Simmons, who has rendered valuable service on the publication committee for several years, was appointed vice-chairman of the committee.

The publication committee continues to welcome comment and criticism from all Institute members.

MEMBERSHIP COMMITTEE

The membership committee has endeavored to improve its effectiveness this year by laying increased stress on better organization of its various groups, thereby obtaining better co-ordination of effort and less duplication of work among the many members assigned to this activity. The national committee duties were outlined in

Table III. Membership Statistics for the Fiscal Year Ending April 30, 1940

	Honorary	Fellow	Member	Six-Year Associate	Associate	Total
Membership on April 30, 1939	9	722	4,392	5,726	5,756	16,605
Additions						
Transferred		58	171	515		
New members qualified			127	25	1,472	
Former members reinstated		1	3	16	12	
	9	781	4,693	6,282	7,240	
Deductions						
Died	1	10	47	37	8	
Resigned			39	140	126	
Transferred			58	151	535	
Dropped		4	54	230	352	
	1	14	198	558	1,021	
Membership on April 30, 1940	8	767	4,495	5,724	6,219	17,213

Table IV. Number of Applications Received From Enrolled Students and From All Others

Year Ending	From Students	From All Others	Total
April 30, 1940	911	918	1,829
April 30, 1939	849	872	1,721
April 30, 1938	739	932	1,671
April 30, 1937	716	1,040	1,756
April 30, 1936	631	946	1,577

Table V. Number of Enrolled Students

April 30, 1940	5,517 (2,991)
April 30, 1939	5,242 (2,271)
April 30, 1938	5,037 (2,428)
April 30, 1937	4,503 (2,249)
April 30, 1936	4,049 (1,991)

Following the number of students reported for April 30 of each year is indicated within parentheses the number of new applications received during that year; the difference between this number and the reported total, of course, reflects the number of renewals of Student enrollment for the corresponding period.

Table VI. Number of Members in Section Territory Reinstated

August 1, 1939 to April 30, 1940	249
Year Beginning August 1, 1938	354
Year Beginning August 1, 1937	325
Year Beginning August 1, 1936	503
Year Beginning August 1, 1935	663

a communication from the chairman at the start of the committee year.

The Section membership committees were supplied copies of specially prepared instructions and guides to assist their early organization into efficient working groups. A census of Section membership committee personnels was requested early in the year to stimulate early organization in the Sections and to permit the Institute to give these men recognition for the effort they put forth each year. Accordingly, the complete Section membership committee lists were published in the January 1940 issue of ELECTRICAL ENGINEERING. The membership committee is grateful to the publication committee for its full co-operation in this effort.

As of January 1940, there were 494 men assigned to Section membership committees with an unknown additional number working on Section subcommittees.

In the national committee ten vice-chairmen continued as the membership "chiefs" of their respective Districts, and a small group of five members-at-large was set up for advice and assistance to the chairman. The committee held two meetings during the year at headquarters.

The committee has gone further in the direction of personalizing membership work both to bring the Institute closer to its Section committees and to bring the entire membership closer to the Institute. The Sections have been asked to give personal recognition to each new member at his first meeting and to give recognition to the proper membership committeeman responsible for obtaining the new addition to the Section at the same meeting.

The chairman has written personally, so far as was possible, to each member who desired information concerning membership matters, and has received many letters indicating favorable reaction to this policy.

Table VIII. Memberships Fully Paid

Year	Membership as of April 30	Number of Members Fully Paid as of April 30	Per Cent Fully Paid
1940	17,213	14,997	87.1
1939	16,605	14,371	86.5
1938	16,078	14,127	87.9
1937	15,308	13,439	87.8
1936	14,600	12,446	85.2
1927*	18,344	16,247	88.6

* Year of maximum membership.

Table IX. Record of AIEE Membership

Total Membership May 1		Total Membership May 1		Total Membership May 1	
1884	71	1904	3,027	1923	15,298
1885	209			1924	16,455
1886	250	1905	3,460		
1887	314	1906	3,870	1925	17,319
1889	333	1907	4,521	1926	18,158
		1908	5,674	1927	18,344
1890	427	1909	6,400	1928	18,265
1891	541			1929	18,133
1892	615	1910	6,681		
1893	673	1911	7,117	1930	18,003
1894	800	1912	7,459	1931	18,334
		1913	7,654	1932	17,550
1895	944	1914	7,876	1933	17,019
1896	1,035			1934	15,230
1897	1,073	1915	8,054		
1898	1,098	1916	8,202	1935	14,269
1899	1,133	1917	8,710	1936	14,600
		1918	9,282	1937	15,308
1900	1,183	1919	10,352	1938	16,078
1901	1,260	1920	11,345	1939	16,605
1902	1,549	1921	13,215	1940	17,213
1903	2,229	1922	14,263		

The assistance of the student counselors was solicited in January and February in an effort to encourage a maximum number of eligible Enrolled Students to apply for Associate grade. The counselors' help was very valuable, and the committee extends its appreciation to them.

It is the feeling of the committee that the improvements attained in organization were effective and well worth the effort. Evidence of this may be seen in tables III and IV, where it is shown that the total membership has increased from 16,605 to 17,213, and that 1,829 applications were received during the year ending April 30, 1940. The number of applications shows an increase of over 6 per cent above the same figure last year.

Table V shows another increase in the number of Enrolled Students. This is important since about half of the applications for membership come from the Students, as will be seen in table IV.

Table VI shows a continuing decrease in the number of delinquents reinstated, as may be expected unless business conditions become more adverse over a considerable period of time. This is due to the number of probable prospects being continually reduced.

Table VII shows about the same conditions as last year, though table VIII indicates a small improvement in the percentage of the members with dues fully paid.

DEATHS

The deaths of 103 members reported during the year are listed in table X.

BOARD OF EXAMINERS

The board of examiners held 11 meetings during the past year, averaging about two and one-half hours each, and considered 4,250 cases, divided as shown in table XI.

The Procedure of the Board. It has become increasingly apparent to the board of examiners that the membership of the Institute needs to know more of the requirements in the constitution and bylaws with regard to membership grades as well as the technique of the board in handling applications for admission and transfer. Evidence of this is found in requests for procedure whereby the board could give advance indications of likely action in cases in which certain Sections are particularly anxious to avoid embarrassment to the applicants and to the membership and transfer committees. Realizing that every effort should be made to make the problems and procedures of the board of examiners better understood by the membership, it was voted that the following statement should be incorporated in this year's annual report to the board of directors.

A study of the "advance or informal opinion" suggestion makes it evident that the motivating factor is doubt as to eligibility, usually with regard to transfer to the grade of "Fellow", of men of local prominence. An attempt to provide for this situation is evidenced by the adoption in 1923 of the revision of the bylaws legalizing a "transfer proposal" form, which now, however, applies only to Member grade. The practical application of that proposal form immediately resulted in serious trouble. Due to local pressure, the signatures of endorsers were obtained on the proposal form, yet on the confidential reference blanks sent out by headquarters, as required by the constitution, the former endorsers in certain instances failed to recommend transfer. Again, the abbreviated records supplied on the proposal forms were not sufficient in many cases to permit the examiners to form even informal opinions on eligibility. Finally, men were proposed for advancement who had no desire to transfer, and

Table VII. Membership of the Institute, April 30, 1940

Of the 17,213 members reported for April 30, 1940, 14,997 are fully paid to April 30, 1940. The balance of 2,216 are divided into the following groups:

1. Members owing dues to April 30, 1939
Total number of members who have not acted upon resolution of board of directors adopted in January 1940 providing an extension of time for payment of dues 634

2. Members owing dues to April 30, 1940 1,582

(During the period May 1 to 15, 1940, 326 members have paid dues to April 30, 1940, reducing the total to 1,256.)

when word reached them of the action taken they expressed their objections to the procedure in no uncertain terms. In one notable case, where the examiners on consideration of the complete formal application felt compelled to reverse their informal decision based on a "proposal" record, a Section secession threat resulted. The board of examiners has therefore not encouraged the "advance opinion or proposal form" as an ineffective mechanism for obtaining the advance of applicants to appropriate and constitutionally authorized grades of membership.

The suggestion that unfavorable action be postponed until some local group has been contacted has also been studied on many occasions by many boards. As a matter of fact, the suggested procedure has been practiced as far as practical by the examiners for many years, within the limits of the constitution and bylaws. A considerable part of the correspondence of the secretary of the board of examiners is concerned with building up of complete professional records of applicants and obtaining the required number and grade of references. This correspondence is with local Section officers where the situation warrants such action, otherwise it is with the applicants or their references. The examiners believe, however, that to restrict the board in its present freedom to accommodate the method of inquiry to the circumstances in each case would lead to added difficulties, particularly in transfer cases. On all direct admission applications, the character question is involved; they are therefore posted and are the subject of general knowledge in advance of examiners action. On the contrary, transfer applications are frequently transactions solely between the applicants and the Institute; they are not published in any way and are otherwise known only to the supporting references. To divulge likelihood of unfavorable action to local officers or committees would be seriously objected to by many as a violation of a confidential privilege accorded to members. It might easily defeat the desired objective of encouraging meritorious transfers.

The suggestion has been made that the board of examiners be instructed to report tentative decisions to the local Sections in advance of final action on cases of direct admission or transfer to higher grades. The board feels, however, that stipulation of such procedure would tend to limit freedom of final action in accordance with the requirements of the constitution and bylaws and thus seriously curtail the independence and hamper the effectiveness of the board in its function of maintaining a high standard of Institute membership in the upper grades. It should be pointed out here that most of the members of the board of examiners have been active in Sections, local and national membership committees, over a long period of years and have had full experience in the problems now before us. To this they have added the experience on the board of examiners in dealing with many difficult cases. The board, after giving careful consideration to these important problems, therefore, does not look with favor upon the prescription of a procedure which would require a divulgement of probable action based on incomplete information about the applicant. Sponsors of such applicants often have receded from an advocacy which was founded on an incom-

Table X. Deaths of AIEE Members Reported During the Fiscal Year

Name	Date of Election	Date of Death	Grade at Death	Obituary Notice in Electrical Engineering
Allen, Edwin W.	Associate '03	Jan. 1, 1940	Fellow	Feb. 1940, p. 90
Allensworth, H. R.	Associate '04	Nov. 29, 1939	Member	Feb. 1940, p. 91
Arnold, H. S.	Associate '11	July 24, 1939	Associate	Jan. 1940, p. 49
Ashbrook, R. B.	Associate '20	Aug. 15, 1939	Member	Nov. 1939, p. 492
Bayha, L. H.	Associate '33	Sept. 17, 1939	Associate	Dec. 1939, p. 541
Belshe, R. L.	Associate '35	May 24, 1939	Associate	July 1939, p. 323
Beugler, H. M.	Associate '03	July 16, 1939	Member	Sept. 1939, p. 398
Bourath, J. N.	Associate '21	May 13, 1939	Associate	Aug. 1939, p. 363
Bryant, R. B.	Associate '09	May 21, 1939	Associate	Aug. 1939, p. 363
Burke, James	Associate '93	Jan. 21, 1940	Fellow	March 1940, p. 134
Carnahan, G. C.	Associate '20	April 15, 1939	Associate	Aug. 1939, p. 363
Cleaves, B. F.	Associate '23	July 30, 1939	Associate	Sept. 1939, p. 398
Clements, F. W.	Associate '08	Dec. 12, 1939	Associate	May 1940, p. 217
Cook, Leonard	Associate '39	March 29, 1940	Associate	May 1940, p. 217
Cornford, F. J.	Associate '23	Nov. 5, 1939	Associate	Jan. 1940, p. 50
Cox, F. P.	Associate '01	Nov. 30, 1939	Fellow	Jan. 1940, p. 50
Cramp, William	Member '26	April 20, 1939	Member	June 1939, p. 280
Crosby, G. L.	Associate '15	Dec. 2, 1939	Member	Jan. 1940, p. 50
Crozier, H. W.	Associate '03	April 13, 1939	Member	June 1939, p. 280
Davis, C. W.	Member '29	Sept. 16, 1939	Member	Nov. 1939, p. 492
Davis, G. S.	Associate '04	Dec. 29, 1939	Member	April 1940, p. 174
Denehy, H.	Associate '12	Feb. 21, 1940	Associate	May 1940, p. 217
de Sousa, A. M.	Associate '28	1939	Associate	Oct. 1939, p. 445
Dill, G. C.	Associate '13	April 1, 1939	Member	June 1940, p. 258
Dodge, O. G.	Associate '93	June, 1936	Member	Feb. 1940, p. 91
Doherty, H. L.	Associate '98	Dec. 27, 1939	Fellow	Feb. 1940, p. 90
Donnelly, A. L.	Associate '18	1939	Associate	Jan. 1940, p. 50
Dozey, F. S.	Associate '26	Jan. 12, 1940	Associate	March 1940, p. 135
Fields, W. S.	Associate '25	March 9, 1939	Associate	June 1939, p. 281
Finley, J. H.	Associate '27	March 10, 1939	Associate	July 1939, p. 323
Firman, L. D.	Associate '06	1939	Member	Nov. 1939, p. 492
Foster, S. C.	Associate '11	April 22, 1939	Associate	Aug. 1939, p. 363
Fung, J. T. S.	Associate '35	1939	Associate	Dec. 1939, p. 541
Garton, W.	Associate '05	Sept. 15, 1939	Associate	Dec. 1939, p. 540
Garvin, J. P.	Associate '23	May 12, 1939	Member	Sept. 1939, p. 398
Gibson, J. J.	Associate '02	May 6, 1939	Fellow	June 1939, p. 279
Graef, W. H.	Associate '08	Feb. 20, 1940	Member	May 1940, p. 217
Gravell, J. H.	Associate '17		Associate	Feb. 1940, p. 90
Gray, E. T.	Associate '23	July 6, 1939	Associate	Sept. 1939, p. 398
Hagenbuch, L. G.	Associate '34	Oct. 1, 1939	Associate	Dec. 1939, p. 541
Harrington, A. L.	Associate '07	Nov. 15, 1939	Associate	March 1940, p. 135
Hecker, A. E.	Member '30	June 1, 1939	Member	Jan. 1940, p. 50
Henry, I. W.	Member '36	April 25, 1940	Member	June 1940, p. 257
Heskett, Thomas	Associate '04	March 1939	Member	June 1939, p. 280
Hirt, E. L.	Associate '18	May 28, 1939	Associate	July 1939, p. 322
Hogshead, C. C.	Associate '35	March 14, 1939	Associate	Jan. 1940, p. 50
Honegger, Arnold	Associate '15	June 20, 1939	Member	Nov. 1939, p. 492
Hopkins, I. B.	Associate '37	Jan. 12, 1940	Associate	April 1940, p. 174
Horan, Michael	Associate '29	Jan. 19, 1940	Associate	May 1940, p. 218
Hughes, C. P.	Member '39	July 7, 1939	Member	Sept. 1939, p. 399
Jacobi, W. O.	Associate '10	April 10, 1939	Member	Aug. 1939, p. 362
Johnston, D. H.	Member '28	Sept. 12, 1939	Member	Dec. 1939, p. 541
Kennelly, A. E.	Associate '88	June 18, 1939	Fellow	July 1939, p. 322
Knight, C. D.	Associate '05	Feb. 28, 1940	Member	April 1940, p. 173
Komaru, Toda	Associate '20	March 14, 1939	Associate	Aug. 1939, p. 363
Kramer, C. H.	Associate '20	Feb. 28, 1939	Member	July 1939, p. 323
Lagomasino, J.	Associate '38	1940	Associate	June 1940, p. 258
Little, A. P.	Associate '09	Dec. 28, 1939	Member	March 1940, p. 135
Little, C. W. G.	Associate '96	1939	Associate	Nov. 1939, p. 492
Livingston, J.	Associate '98	Oct. 10, 1939	Associate	Dec. 1939, p. 541
Marks, L. B.	Associate '90	Nov. 22, 1939	Fellow	Jan. 1940, p. 50
McRae, W. R.	Member '17	1939	Member	Dec. 1939, p. 540
Merizal, G.	Associate '12	1939	Associate	Aug. 1939, p. 363
Mesick, C.	Associate '03	May 25, 1939	Member	July 1939, p. 323
Mountain, J. T.	Associate '04	April 16, 1939	Fellow	July 1939, p. 323
Mowry, H. W.	Associate '18	Dec. 10, 1939	Member	Feb. 1940, p. 91
Nielsen, W. C.	Associate '37	Oct. 4, 1939	Associate	Feb. 1940, p. 91
Norris, H. H.	Associate '03	April 14, 1940	Fellow	May 1940, p. 217
Nunn, P. N.	Associate '95	Oct. 27, 1939	Member	Dec. 1939, p. 540
O'Brien, P. O.	Associate '24	March 10, 1940	Associate	May 1940, p. 217
Ost, P. J.	Member '23	Dec. 30, 1939	Member	March 1940, p. 135
Piek, Stefaan	Associate '06	Dec. 13, 1939	Associate	Feb. 1940, p. 90
Popkin, M. E.	Associate '19	Jan. 29, 1940	Associate	March 1940, p. 135
Pringle, D. R.	Associate '07	Aug. 4, 1939	Associate	Oct. 1939, p. 445
Ralston, E. G.	Associate '21	April 17, 1939	Member	June 1939, p. 280
Ramsay, J. W.	Associate '36	July 22, 1939	Member	Sept. 1939, p. 398
Renshaw, E. N.	Associate '18	May 16, 1939	Associate	July 1939, p. 323
Reynolds, W. H.	Associate '04	Jan. 12, 1940	Member	March 1940, p. 135
Robertson, W. L.	Associate '05	Nov. 17, 1939	Associate	Jan. 1940, p. 50
Roth, Edouard	Associate '18	April 29, 1939	Associate	June 1939, p. 280
Rugg, W. S.	Associate '02	April 25, 1940	Member	June 1940, p. 257
Sawyer, R. E.	Associate '30	Oct. 29, 1939	Associate	Jan. 1940, p. 50
Scoville, E.	Associate '12	Jan. 14, 1940	Member	March 1940, p. 135
Servos, F. M.	Associate '19	July 8, 1939	Member	Sept. 1939, p. 397
Sessions, A. F.	Member '37		Member	Feb. 1940, p. 91
Seyfert, S. S.	Associate '05	Dec. 11, 1939	Member	Jan. 1940, p. 49
Shannon, J. H.	Member '25	Jan. 16, 1940	Member	March 1940, p. 135
Silbert, R. H.	Associate '17	1939	Member	Nov. 1939, p. 493
Smith, G. H.	Associate '20	Sept. 10, 1939	Member	Oct. 1939, p. 445
Smith, J. C.	Associate '03	June 24, 1939	Fellow	Aug. 1939, p. 362
Spangenberg, O. C.	Associate '16	June 6, 1937	Associate	Sept. 1939, p. 398

(*Continued on next page*)

Table X (Continued). Deaths of AIEE Members Reported During the Fiscal Year

Name	Date of Election	Date of Death	Grade at Death	Obituary Notice in ELECTRICAL ENGINEERING
Steele, G. F.	Associate '10	June 25, 1939	Member	Aug. 1939, p. 362
Stevens, W. C.	Associate '11	May 15, 1939	Fellow	July 1939, p. 322
Storms, C. A.	Associate '26	Aug. 21, 1939	Member	Oct. 1939, p. 445
Taggart, J. E.	Member '37		Member	April 1940, p. 173
Tibbetts, F. H.	Member '30	August, 1938	Member	July 1939, p. 322
Trudgian, Wm.	Associate '27	Sept. 19, 1939	Associate	Nov. 1939, p. 493
Vanderpoel, W. K.	Associate '08	Oct. 21, 1939	Member	Dec. 1939, p. 540
Wagner, G. J.	Member '20	Sept. 2, 1939	Member	Dec. 1939, p. 540
Waring, S. B.	Associate '35	1939	Associate	Nov. 1939, p. 493
Wilkinson, G. D.	Associate '25	July 5, 1939	Associate	Sept. 1939, p. 398
Wood, B. D.	Associate '21	Nov. 9, 1939	Member	Dec. 1939, p. 540
Woodcock, L. R.	Associate '09	July 1, 1939	Member	Sept. 1939, p. 397

plete record of professional attainment. On the contrary, the board believes the responsibilities and necessarily confidential procedures of the board would be better appreciated by the members if more emphasis were placed on the importance of filing complete professional records on the initial applications for direct admission or transfer to higher grades.

To correct any false impression as to the number of applications for admission and transfer on which the examiners have felt compelled to rule unfavorably, a summary for the last ten-year period, 1931–40, is presented in table XII.

It should be noted that the figures in table XII show a total rejection of Fellow grade applications over the ten-year period of only 29. The Member rejections (about 11 per cent) are apparently due in part to a failure to appreciate the technical experience required for that grade and the tendency of applicants to select Member grade merely because they have passed the 27-year lower-age limit. Comparison of conditions before and after the increase of Associate dues at the end of the six-year period seems to indicate that it has also been a potent factor in developing ineligible Member applications.

Table XI. Applications for Admission and Transfer

Applications for Admission			
Recommended for grade of Associate	1,724		
Re-elected to the grade of Associate	86		
Not recommended		4	1,814
Recommended for grade of Member	122		
Re-elected to the grade of Member	12		
Not recommended		44	178
Recommended for grade of Fellow	1		
Re-elected to the grade of Fellow	0		
Not recommended		0	1
Applications for Transfer			
Recommended for grade of Member	167		
Not recommended		24	191
Recommended for grade of Fellow	53		
Not recommended		3	56
Students			
Recommended for enrollment as Students			2,010
Total			4,250

Table XII. Rulings by Examiners 1931–40

	Recommended	Not Recommended
Admissions		
Associates	11,426	183
Members	1,078	284
Fellows	23	10
Transfers		
Members	1,781	184
Fellows	284	19

STANDARDS COMMITTEE

The four standards co-ordinating committees organized during the past year have devoted themselves to the tasks assigned to them.

Committee No. 1, Reference Values for Standards, has collected extensive data relating to existing practices on reference values. A paper covering this subject will be presented at the summer convention.

Committee No. 2, Standard Voltages and Currents, is keeping in close touch with the activities of the corresponding NEMA and EEI committees dealing with voltages above 100. Furthermore, a subcommittee has been organized to study the possibilities of standardization for voltages below 100. This subcommittee has collected considerable information on existing practices, and is ready to co-operate with the newly organized ASA sectional committee on the same subject.

Committee No. 3, Insulation Testing and Co-ordination, has appointed a group of AIEE representatives to work with the NEMA and EEI committees handling insulation co-ordination. In addition, a subcommittee on insulation testing and evaluation has been organized, which for the present is collecting data on existing practices in insulation testing and on methods for evaluating insulation. Another subcommittee on the standardization of wet tests has just been organized, and will attempt to unify greatly divergent standards provisions now existing.

Committee No. 4, Basic Principles for Rating of Electrical Machinery and Apparatus, sponsored several papers relating to its activity during the 1939 AIEE summer convention and at the District meeting in Scranton, Pa. The committee has had several meetings, and worked out a complete revision of standard No. 1, General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery and Apparatus, which has been approved by the standards committee. The co-ordinating committee is now undertaking a study of short-time and intermittent ratings and loads, and a number of papers covering the subject will be presented at the summer convention.

In addition to these four committees, two new co-ordinating committees have been organized, namely: No. 5, Basic Theories and Units, and No. 6, Interference, Sound, and Noise Problems. Both committees are preparing to start actual work.

The first topic requiring the consideration of committee No. 5 will be the relative merits of the rationalized versus the unrationalized system of mks units, and the advisability of the endorsement of the preferred system by the Institute. The article "Revision of Electrical Units" by E. C. Crittenden in the April 1940 issue of ELECTRICAL ENGINEERING bears on this topic.

The co-ordinating committees, in addition to carrying on their major activities, have been active in reviewing various standards submitted to the standards committee for approval, to assure the maximum uniformity and co-ordination of these standards with others in existence. Additional co-ordinating committees may be organized as the desirability or need for other activities becomes apparent.

A decided increase in the activities of various sectional committees of ASA concerned with problems in the electrical field was noted during the year, and this called for the appointment of individual Institute representatives as well as AIEE delegations. Among such activities may be mentioned the following: Vacuum Tubes for Industrial Purposes—*C*60; Wire and Sheet Metal Gages—*B*32; Storage Batteries—*C*40; Industrial Lighting—*A*11; Radio—*C*16; Dry Cells—*C*18; and Carbon and Graphite Brushes—*C*64.

The chief development in published standards and one of great interest to the Institute was the issuance by ASA of the Proposed Standard for Transformers. This publication, it is hoped, will shortly be approved as an American standard. It replaces AIEE standards Nos. 12, 13, 14, 100, and the Test Code for Transformers. In addition, three revisions of existing Institute standards were submitted and will be published, as follows: General Principles Upon Which Temperature Limits Are Based in Rating of Electrical Machinery; Measurement of Test Voltages in Dielectric Tests; Air Switches and Bus Supports.

In line with the attitude of the standards committee during recent years in urging greater activity by the technical committees in the standards field, a plan has been suggested which should not only lead to a co-ordination of the standards work of those committees, but also provide for the continued development of that work from year to year.

UNITED STATES NATIONAL COMMITTEE OF THE IEC

The United States National Committee has been saddened during the past year by the death of its honorary president, Doctor Arthur E. Kennelly, and also of James Burke, one of its most prominent members and a past president of the International Electrotechnical Commission. Doctor Kennelly, who was also an honorary president of the commission, served as technical ad-

visor to the USNC on several subjects. The loss of these two valued members will be keenly felt by the USNC.

The 1939 annual meeting of the USNC elected Doctor Clayton H. Sharp honorary president of the committee and E. C. Crittenden, representing the National Bureau of Standards, president. L. F. Adams, representing the National Electrical Manufacturers Association, was elected vice president and Doctor H. S. Osborne, representing the AIEE, was re-elected vice president and treasurer.

Because of the European situation, the work of the International Electrotechnical Commission, and consequently of the USNC, has been considerably curtailed. However, the general secretary of the IEC has advised the national committees that the central office intends to carry on as much work by correspondence as possible under existing conditions, and hopes to issue, as provisional IEC recommendations, those documents which had been circulated under the six months rule prior to the beginning of the war. These are: Specifications for Transformers (excluding instrument and testing transformers); Specifications for the Resistivity of Aluminum; Specifications for Porcelain Insulators for Overhead Lines of 1,000 V and Upwards; Specifications for Safety Requirements for Electric Mains-operated Radio Receiving and Amplifying Apparatus; Revision of Publication 42, Part 3, Graphical Symbols for Weak-current Installations; Rules for the Measurement of Test-Voltages by Sphere-Gaps in Dielectric Tests, Appendix to IEC Publication No. 46 on Steam Turbines—Supplementary Notes to Section 4 Instruments and Methods of Measurement.

The meetings of the IEC advisory committees which had been scheduled for September 1939 in New York have been indefinitely postponed. However, these meetings will be held in New York eventually, after world conditions have returned to normal.

Hydraulic Turbines, IEC 4. The USNC, as secretariat of the IEC committee on hydraulic turbines, has prepared proposed specifications for hydraulic turbines including rules for acceptance tests. These documents have been sent to the central office of the IEC for transmission to the national committees for their comments.

Rating of Rivers, IEC 14. At the last meeting of the committee of action of the IEC, held in Paris in June 1939, it was agreed by implication that the IEC project on rating of rivers should be abolished because the committee had ceased to function. The USNC has registered with the central office of the IEC an objection to the abolishing of this committee, with the information that there appears to be a good likelihood that an American standard will be adopted and that a further effort should be made to reach international agreement.

Rules for the Measurement of Test-Voltage by Sphere Gaps in Dielectric Tests. Early in 1939, there was circulated to the national committees of the IEC a document giving draft rules for the measurement of test voltage by sphere gaps in dielectric tests, which had been prepared following the Torquay meeting in 1939. Comparison showed considerable differences in these proposed IEC standards from the standards in common use in this country. It was deemed desirable, therefore, that the matter be reopened within the IEC sphere gap subcommittee, and a meeting was arranged in Paris in July 1939. This meeting was attended on behalf of the USNC by P. L. Bellaschi. It was agreed that certain modifications should be made in the proposed standards. The modifications were to be carried out by the British, German, and American representatives. This decision has opened the question of sphere-gap standards again in such a way that it will be possible for a general compromise satisfactory to the USNC to be arrived at.

COMMITTEE ON PLANNING AND CO-ORDINATION

The comprehensive report of the committee dated April 3, 1939, was presented at the meeting of the board of directors held on May 26, 1939. Recommendations regarding discussion of social and economic questions, presentation and publication of papers, financial support of research, and nominations procedure were approved. The president was authorized to refer any or all of the remaining topics in the report to regular or special committees for further study and report.

The committee held meetings in October and January, and considered many topics which had been referred to it by the board of directors, or the president, or received from other sources. It made recommendations to the board of directors on a considerable number of matters involving a wide range of Institute activities, and has others still under consideration. Additional topics have come to it, and an all-day meeting will be held on May 23.

The committee, as usual, invited District and Section officers to submit requests for any national conventions and District meetings desired in the calendar year 1941, and prepared a schedule of such meetings which was approved by the board of directors in January.

COMMITTEE ON LEGISLATION AFFECTING THE ENGINEERING PROFESSION

At the start of the administrative year, the committee on legislation affecting the engineering profession absorbed the special committee on model law for registration of engineers. In June 1939, the AIEE model law was endorsed by the Board of Directors. Committee activity during the 1939–40 year has been limited to following up the discussion of this law and correspondence with engineers regarding proposed legislation in the various states.

Copies of the AIEE model law were circulated to various groups for comment. Much favorable comment has resulted and a small amount of adverse criticism. In some states principles underlying the AIEE model law are being drafted into proposed legislation.

Following the committee's recommendation, a number of AIEE Sections have appointed committees on legislation to keep posted regarding licensing activity in their states and to support or oppose according to local opinion. It is highly desirable that all Sections appoint such committees. Sections should afford all AIEE members opportunity to review personally proposed legislation, so that any position taken by a Section may be the considered majority opinion after full discussion. It should also be recognized that the scope of such committees should be confined to legislation affecting the profession.

The AIEE committee on legislation affecting the engineering profession desires to be kept informed by Sections on local activity in licensing.

COMMITTEE ON CONSTITUTION AND BYLAWS

The committee interpreted several sections of the bylaws referred to it, resulting in amendments to the bylaws. There were no meetings of the committee, the work being conducted by correspondence.

COMMITTEE ON ECONOMIC STATUS OF THE ENGINEER

The committee was very glad to cooperate with the similar committee of The American Society of Mechanical Engineers under the chairmanship of Dean C. J. Freund, in a consideration of unionization of engineers. This took the form of a paper on this topic by James H. Herron in *Mechanical Engineering* for November 1939, and discussions in the January 1940 issue of the same magazine. Professor Sorensen has contributed a discussion which is planned for the June issue of ELECTRICAL ENGINEERING.

The chairman of the Institute committee was appointed a member of Mr. Bickelhaupt's AEC committee on engineering and allied technical professions. Since similar appointments were made representing the American Society of Civil Engineers, the ASME, and the Washington Society of Engineers, an opportunity was presented to coordinate the efforts of the several committees dealing with the economic status of the engineer.

During the year great interest developed in a request for knowledge of the classification and salaries of electrical engineers particularly on the part of the younger members of the Institute and of faculty and industrial personnel officers. Analyses made by Dean F. M. Feiker of the distribution of engineers by industry indicate that more than 40 per cent of all civil engineers are employed by federal, state, and local governments; fewer than 3 per cent of electricals and mechanicals are so employed. Thus there is a distinct difference in the personnel problems of the three Founder Societies, and the subject is a very difficult one. Nevertheless, the Pittsfield Section of the Institute has studied the matter intensively during the year, and has requested more data and information. In order to explore the field and see if there is any basis for uniformity in the classifications and ranges in various industries which might be fairly representative of the profession as a whole, President Farmer has appointed a committee under the chairmanship of A. C. Stevens to obtain information and report its findings to the board.

COMMITTEE ON AWARD OF INSTITUTE PRIZES

Four national and eight District prizes were awarded for papers presented during the calendar year 1939 and for the student papers presented during the academic year ending June 30, 1939.

The committee considered a large number of eligible papers which were of a high quality, and, in determining the awards for the national best paper prizes and initial

paper prize, it had the benefit of the gradings and recommendations of the technical committees which had reviewed the papers. In addition to the national paper prize awards, six other papers were given honorable mention.

On recommendation of the committee on award of institute prizes, the board of directors approved changes in the rules governing the award of all District prizes. These changes permit consideration of all papers for each prize subsequent to the periods covered by the last previous awards.

COMMITTEE ON SAFETY

The committee on safety continued the discussion of a number of subjects related to electrical safety during the year. One meeting of the committee was held during the year, and other matters have been handled through correspondence.

A paper on "Safe Practices in College Laboratories," prepared by M. S. Coover of Iowa State College, was presented at the annual meeting of the Society for the Promotion of Engineering Education in June 1939. The committee understands that the National Safety Council is now preparing a pamphlet on this subject for inclusion in its standard safe practice series.

The committee was represented by its chairman at an open meeting held during the National Safety Congress in October 1939, to review the NSC Safe Practice Pamphlet on Portable Electrical Hand Tools, prior to the development of a revised edition.

Inasmuch as it has not been practicable to print an AIEE pamphlet on artificial respiration due to the expense involved, an effort was made to secure sufficient copies of such material from the American Red Cross. A review of the Red Cross material indicated that it contained many phases of first aid, in addition to artificial respiration instruction, and was probably too voluminous for the purpose intended by the committee. Copies of a small pamphlet issued by the American Gas Association and the Edison Electric Institute will be asked for by the committee for use in making contacts with colleges and Student Branches concerning the development of resuscitation instruction.

A subcommittee has been appointed to develop further contacts with colleges and Student Branches in co-operation with the committee on Student Branches, and another subcommittee has been appointed to develop further contacts with the AIEE Sections on matters pertaining to electrical safety.

After a discussion of accidents in the medical field, the chairman and secretary of the committee agreed to inquire, through individual contact, regarding any steps which may have been taken by the medical fraternity to reduce accidents in handling electrical medical equipment.

COMMITTEE ON AUTOMATIC STATIONS

The committee on automatic stations held two meetings during the year, and sponsored the presentation of two papers at the summer and Pacific Coast convention and one paper at the winter convention.

COMMITTEE ON BASIC SCIENCES

The committee on basic sciences has reviewed eight papers, and has four in process of review. One-half of a session at the winter convention was sponsored by the committee, and it will provide papers for one-half of a session at the summer convention. A technical conference on definitions was held at the winter convention, and a conference on nonlinear analysis will be held at the summer convention.

COMMITTEE ON COMMUNICATION

Under the sponsorship of the committee on communication 16 technical papers on communication were presented at the summer-Pacific Coast convention, the winter convention, and the District meetings in Springfield and Minneapolis, and technical conferences were held at the two national conventions. Much attention has been given to radio subjects, and 8 of the 16 papers mentioned above deal specifically with radio. Several others are of interest to specialists in that field. A communication session at the summer-Pacific Coast convention was sponsored jointly with the Institute of Radio Engineers, and another joint session will be held at the 1940 Pacific Coast convention. A paper on frequency modulation, with demonstrations, will be presented at the summer convention.

COMMITTEE ON EDUCATION

The principal effort of this committee has been devoted to considering, planning, and putting into effect a program which might be continued into future years. As early steps in this direction, an outline of suggested activities was considered, and an inquiry regarding the desirability of organizing committees on education in the Sections was sent to the Section chairmen. On account of the generous response from the Sections and their keen interest in educational activities, a subcommittee was formed to secure detailed information on efforts of an educational nature intended to aid young engineers, and to make it available to all Sections. Two other subcommittees were organized: one to study vocational guidance activities of the Sections, and the other to secure, for publication in ELECTRICAL ENGINEERING, papers of an educational character of special interest to younger members. The committee hopes to make a significant contribution at the 1941 summer convention.

COMMITTEE ON ELECTRICAL MACHINERY

Five of the seven subcommittees of this committee have been active in developing and revising standards and test codes. The committee supplied three papers on "Hydrogen-Cooled Turbine Generators" for the North Eastern District meeting held in Springfield, Mass., in May 1939, and sponsored one session at the summer-Pacific Coast convention, and two sessions at the winter convention. A session and a technical conference on test codes at the 1940 summer convention will be sponsored by the committee.

COMMITTEE ON ELECTRIC WELDING

A session on welding sponsored by this committee at the 1940 winter convention created a large amount of interest. The committee has been devoting itself to the advancement of an educational program for extending co-operation among the manufacturers of welding equipment, the users, and the power companies to the end that good welding results may be secured at minimum first cost and operating cost. Parts I and II of a subcommittee report entitled "Power Supply for Resistance-Welding Machines" was presented at the winter convention, and several thousand reprints are being distributed.

COMMITTEE ON ELECTROCHEMISTRY AND ELECTROMETALLURGY

The committee held two meetings, and sponsored a joint symposium on power in the electrochemical industry by the Niagara Frontier Section of the Institute and the Niagara Falls section of the Electrochemical Society. It is planning a technical session for the 1941 winter convention in co-operation with the American Society of Metals. A subcommittee is investigating the effects of overvoltage in connection with large electrochemical and electrometallurgical installations.

COMMITTEE ON PRODUCTION AND APPLICATION OF LIGHT

A report, "Progress in Production and Application of Light" was published, in the name of the committee, in the December issue of ELECTRICAL ENGINEERING. A demonstration lecture based on the report, together with addresses on lighting of the New York World's Fair and the New York Municipal Airport, constituted a session at the winter convention. The planning of and the soliciting of papers for this program constituted one of the major activities of the committee. The attendance, and the reception of the papers were most gratifying. Several additional papers have been reviewed and approved for presentation at the summer convention. The committee has collaborated with the editor in obtaining special articles for ELECTRICAL ENGINEERING, and has a subcommittee which furnishes items of news interest. It has collaborated with the illumination group of the New York Section in organizing meetings for the discussion of lighting practice and developments in illuminating engineering.

COMMITTEE ON APPLICATIONS TO MARINE WORK

This committee has thoroughly reviewed standard No. 45, "Recommended Practice for Electrical Installations on Shipboard", through the work of 10 subcommittees. The editing committee is now preparing the recommended changes for submission to the standards committee.

COMMITTEE ON INSTRUMENTS AND MEASUREMENTS

The activities consisted primarily of reviews of technical papers, sponsorship of technical sessions at the two national conventions, preparation of reports on various phases of the progress of the art, and revision and extensions of AIEE standards. Material is being prepared for a comprehensive report on "Progress in the Art of Metering" covering electric power metering from its inception to the present day. A report on progress in telemetering is nearing completion. A report on "Wave Form in Dielectric Testing and Power Factor Measurements" was submitted to the standards committee. A revision of Standard No. 4, "Measurement of Test Voltage in Dielectric Tests", was completed and was approved by the standards committee and the board

of directors. The committee also has reviewed several test codes prepared by other Institute technical committees; is compiling a bibliography on dielectric measurements made in the field; and is surveying possible sources of papers on oscillograph technique.

COMMITTEE ON POWER GENERATION

The committee on power generation has sponsored nine technical papers and one committee report for the two national conventions and the District meeting in Springfield. The committee report was for the years 1932–39, and was presented at the winter convention. In the development of plans for next year, two papers, on load swings and stability, and turbine generator governing, are in preparation for informal presentation and discussion at a round-table conference at the summer convention, with the thought that this procedure will aid in the selection of subjects for the 1941 winter convention.

COMMITTEE ON POWER TRANSMISSION AND DISTRIBUTION

One session at the summer-Pacific Coast convention and two sessions at the winter convention were sponsored by the committee. At a meeting of the committee, in September, the discussion of general organization work was followed by a prearranged discussion of engineering developments in the field of the committee. Such discussions have been of great interest to the members. A subcommittee has nearly completed a revision of standard No. 41, Insulators. A joint subcommittee representing three technical committees is preparing standards for bushings. A joint subcommittee is being organized to revise the grounding report prepared in 1931. A subcommittee is studying the advisability of a reorganization of committee on power transmission and distribution to meet present-day needs more effectively.

COMMITTEE ON PROTECTIVE DEVICES

The committee on protective devices has four subcommittees handling important divisions of its activities: circuit breakers, switches, and fuses; lightning arresters; relays; and fault-current-limiting devices. Each has carried on work in the development of standards and in other studies. Several standards have been substantially completed. A fifth subcommittee is cooperating with the committees on electrical machinery and power transmission and distribution. The committee sponsored three sessions on protective devices at the 1940 winter convention, one session and two technical conference papers at the summer-Pacific Coast convention, and one paper at each of the District meetings in Springfield and Minneapolis, with a total of 23 papers presented. A progress report is expected to be ready for the summer convention.

COMMITTEE ON RESEARCH

The principal activity of the committee on research has been in connection with service for the Institute as sponsor of two research projects supported by the Engineering Foundation: No. 66, Stability of Impregnated Paper Insulation, at Johns Hopkins University, and No. 74, Insulating Oils and Cable Saturants, at the Massachusetts Institute of Technology. Consideration has been given to the problems of the research method to ascertain whether there is sufficient interest to justify arrangements for a symposium on this subject. No definite conclusion has been reached. Efforts have been made to continue an activity started several years ago for the preparation of occasional news items on research subjects for ELECTRICAL ENGINEERING.

COMMITTEE ON TRANSPORTATION

The greater part of the work of the committee on transportation has been concerned with arranging to have papers written, reviewed, and presented at conventions. An effort has been made to have them cover the entire field of electrical engineering applied to transportation, and those presented at the winter convention covered a wide range of subjects with excellent discussion. The committee voted to initiate action toward having American tentative standard for railway motors (AIEE No. 11) advanced to status of full standard. At the invitation of the New Zealand Institution of Engineers, the committee also sponsored the preparation of a paper "Modern Rail Transport", by A. M. Wright of the Reading Railroad, for presentation at the New Zealand Centennial Engineering Congress scheduled for February 1940, but later cancelled on account of the war. The paper will be presented at the summer convention.

CHARLES LE GEYT FORTESCUE FELLOWSHIP COMMITTEE

A fellowship for graduate study in electrical engineering was established as a memorial to the late Charles LeGeyt Fortescue "in recognition of his valuable contributions to the electric power industry". The Westinghouse Electric and Manufacturing Company, with which Dr. Fortescue was associated throughout his professional life, set up a trust fund of $25,000 for this purpose.

The income will be administered by the Charles LeGeyt Fortescue fellowship committee of the Institute, and will provide fellowships of $500 or more to candidates selected annually by the committee. A bachelor's degree from an accredited college is a prerequisite, and the holders of the fellowships are expected to carry on their graduate studies in accredited engineering schools and to engage in research problems meeting the approval of the committee.

The first fellowship (1940–41) was awarded in March to Norman Z. Alcock, a senior in Queens University, Kingston, Ontario, who expects to engage in graduate study at the California Institute of Technology, Pasadena.

COMMITTEE ON AWARD OF COLUMBIA UNIVERSITY SCHOLARSHIPS

Seven formal applications were made for this scholarship, and from these the committee selected Cecil Clay Clements, a graduate of Alabama Polytechnic Institute. Mr. Clements qualified and registered in September, and pursued his studies during the winter session. However, in January, his father was taken very sick, and he was obliged to give up his work at Columbia, resigning the scholarship, and returning to his home.

The scholarship was not filled during the spring session because of the difficulty of making transfers in the middle of the academic year.

EDISON MEDAL

The Edison Medal, which is awarded by a committee composed of 24 members of the Institute, was, for 1939, awarded to Philip Torchio "for distinguished contributions to the art of central station engineering and for achievement in the production, distribution, and utilization of electrical energy", and was presented on January 24, 1940, during the winter convention. The medal may be awarded annually for "meritorious achievement in electrical science, electrical engineering, or the electrical arts".

JOHN FRITZ MEDAL

The John Fritz Medal board of award, composed of representatives of the national societies of civil, mining, mechanical, and electrical engineers, awarded the 36th medal (for 1940) posthumously to the late Doctor Clarence F. Hirshfeld, formerly chief of the department of research, Detroit Edison Company, "for notable leadership through research and development in power generation and electric traction and for being a great teacher and friend of men both young and old".

LAMME MEDAL

The Lamme Medal committee awarded the medal for 1939 to Norman W. Storer, retired consulting railway engineer, Westinghouse Electric and Manufacturing Company, "for pioneering development and application of equipment for electrical traction". Arrangements are being made for the presentation of the medal at the summer convention in Swampscott, Mass., June 24–28, 1940. The medal may be awarded annually to a member of the AIEE "who has shown meritorious achievement in the development of electrical apparatus or machinery".

ALFRED NOBLE PRIZE

This prize, established in 1929, consists of a certificate and a cash award of $500 from the income from a fund contributed by engineers and others to perpetuate the name and achievements of Alfred Noble, past president of the American Society of Civil Engineers and of the Western Society of Engineers. It may be made to a member of any of the co-operating societies, ASCE, AIME, ASME, AIEE, or WSE, for a technical paper of particular merit accepted by the publication committee of any of these societies, provided the author, at the time of such acceptance, is not over 30 years of age. The award for 1939 was presented to C. E. Shannon (A'39) for his paper on "A Symbolic Analysis of Relay Switching Circuits".

WASHINGTON AWARD

The Washington Award for 1939 was bestowed upon Daniel Cowan Jackling, "for pioneering in large-scale mining and treatment of low-grade copper ores, releasing vast resources from formerly worthless deposits", and was presented to him at a dinner on April 15, 1940. This award may be made annually to an engineer by the commission of award composed of nine representatives of the Western Society of Engineers and two each of the American Society of Civil Engineers, American Institute of Mining and Metallurgical Engineers, American Society of Mechanical Engineers, and AIEE.

HOOVER MEDAL

The Hoover Medal was established through a trust fund created by a gift from Conrad N. Lauer, and is to be awarded periodically "to a fellow engineer for distinguished public service" by a board representing the national societies of civil, mining and metallurgical, mechanical, and electrical engineers. The fourth recipient of this medal was Doctor Gano Dunn, who was cited as "Long honored by his fellow engineers for professional achievement, he has, beyond that, exemplified high civic purpose and a devotion to public service which have earned for him the Hoover Gold Medal for 1939".

IWADARE FOUNDATION COMMITTEE

No Iwadare lecturer was chosen to go to Japan for the current year, nor has any Iwadare Fellow come to the United States.

EMPLOYMENT SERVICE

The Institute co-operates with the national societies of civil, mining, and mechanical engineers in the operation of the Engineering Societies Employment Service with its main office in the Engineering Societies Building, New York. Offices are operated in Chicago and San Francisco also. In addition to the societies named, others co-operate in certain of the offices as follows: New York—Society of Naval Architects and Marine Engineers; Chicago—Western Society of Engineers; San Francisco—California Section of the American Chemical Society and the Engineers' Club of San Francisco.

The service is supported by the joint contributions of the societies and their individual members who are benefited. In addition to the publication of the employment service announcements monthly in ELECTRICAL ENGINEERING, weekly subscription bulletins are issued for those seeking positions.

An analysis of this employment service as reported to the national societies is given in table XIII.

AMERICAN ENGINEERING COUNCIL

The American Engineering Council has continued to carry on a wide range of activities within the scope of its objectives: "to further the public welfare wherever technical and engineering knowledge and experience are involved, and to consider and act upon matters of common concern to the engineering and allied technical professions".

The broad range of the Council's activities is indicated by the titles of its committees: *Standing*—constitution, by-laws and standing rules, engineering and allied technical professions, finance, membership and representation, publicity and publications, regional activities, and public affairs; *Special*—patents, public works, surveys and maps, engineering economics, and inter-American engineering relations.

At the 20th annual meeting of the assembly held in Washington, D. C., January 11 and 12, 1940, a wide range of subjects received consideration. The 10th conference of secretaries of engineering societies was held on January 11 in connection with the meeting of the assembly.

It was reported at the annual meeting that the joint patent inquiry conducted under the sponsorship of the Council, the National Association of Manufacturers, and the National Industrial Conference Board, with funds supplied by NAM, had been nearly completed, and the report would be submitted to the sponsoring organizations within a few weeks.

A joint committee has been considering the reorganization of the Council in an effort to provide for "a combined professional approach to both public problems and interprofessional problems".

UNITED ENGINEERING TRUSTEES, INC.

This organization is the corporate body which holds title in the name of the four Founder Societies to their joint physical properties, namely, the Engineering Societies Building, the Engineering Societies Library, and the endowment funds of the Engineering Foundation. It operates and manages the Engineering Societies Building and administers certain joint activities of the four Founder Societies.

An abstract of the annual report of the UET, Inc., for the year which ended September 30, 1939, was published in ELECTRICAL ENGINEERING for December 1939, pages 531–2.

During the year, the "History, Charter, and Bylaws" was revised and brought up to date, new heating controls were installed in the Engineering Societies Building, and improvements in the ventilation of the meeting halls were made.

The John Fritz Medal Fund Corporation and the Daniel Guggenheim Medal Fund, Inc., dissolved their corporations and became committees of UET, Inc., which had, for a long period, managed the funds of the former and the books of the latter.

ENGINEERING FOUNDATION

The Engineering Foundation is a joint organization of the national societies of civil, mining and metallurgical, mechanical, and electrical engineers established for "the furtherance of research in science and engineering, and the advancement in any other manner of the profession of engineering and the good of mankind".

A comprehensive abstract of the annual report of the Engineering Foundation for the year which ended September 30, 1939, was published in ELECTRICAL ENGINEERING for December 1939, pages 533–4, including information on each of a wide range of technical researches receiving support or assistance from the Foundation.

The research on "Stability of Impregnated-Paper Insulation" at the Johns Hopkins University is sponsored by the Institute. The work of the "Welding Research Committee" is sponsored by the American Welding Society and the Institute. The Foundation recently has granted support for a research on "Insulating Oils and Cable Saturants", at the Massachusetts Institute of Technology, under the sponsorship of the AIEE.

Assistance in nontechnical matters related to engineering has been granted to the Engineers' Council for Professional Development.

ENGINEERING SOCIETIES LIBRARY

The Engineering Societies Library, which was formed by combining the separate libraries of the four national societies of civil, mining and metallurgical, mechanical, and electrical engineers, and the preparation of a composite card catalog, has been expanded as a single engineering library, which probably constitutes the best collection of its type in the United States.

On September 30, 1939, the library had 146,999 volumes, 7,564 maps, and 4,440 bibliographies. Books, pamphlets, and maps totaling 15,914 were received during the year ending at that time. Current issues of 1,340 periodicals were received. Work progressed rapidly on a classified index to periodicals, and the index now contains more than 242,000 references to articles published since 1927.

Special services rendered by the library include: photoprints, searches, abstracts, translations, bibliographies, book loans by mail, etc. An abstract of the annual report of the library appeared on page 532 of ELECTRICAL ENGINEERING, December 1939.

ENGINEERS' COUNCIL FOR PROFESSIONAL DEVELOPMENT

This council was organized in 1932 to engage in activities leading to the enhancement of the professional status of the engineer. It includes three representatives of each of the seven participating organizations: the national societies of chemical, civil, electrical, mechanical, and mining and metallurgical engineers, the Society for the Promotion of Engineering Education, and the National Council of State Boards of Engineering Examiners.

The principal activities of ECPD include programs for the guidance of young in-

Table XIII. Analysis of Employment Service

Month	Men Registered				Men Placed			
	New York	Chicago	San Francisco	Total	New York	Chicago	San Francisco	Total
1939								
May	143	84	100	327	52	30	12	94
June	181	111	78	370	43	27	17	87
July	176	69	51	298	42	18	9	69
August	156	76	81	315	47	18	22	87
September	141	75	93	309	62	20	23	105
October	217	68	76	361	46	25	23	94
November	219	63	61	343	51	18	15	84
December	165	52	61	278	35	22	26	83
1940								
January	213	68	95	376	51	30	22	103
February	204	83	65	352	45	19	17	81
March	222	80	97	399	50	17	24	91
April	210	89	100	399	51	14	22	87
Total	2,251	918	958	4,127	575	258	232	1,065

dividuals thinking of entering the engineering field, the accrediting of curricula of engineering schools, encouragement and assistance to individuals in their engineering and cultural studies during several years after graduation, and the development of criteria for indicating the attainment of the status of an engineer.

At the annual meeting held on October 20, 1939, the committee on engineering schools presented recommendations on 7 curricula, in four institutions, not previously acted upon, 74 curricula which had been provisionally accredited, and 9 curricula which had been rejected. It reported that 144 out of the total of 150-odd degree-granting engineering institutions had applied for inspection. The actions taken at that meeting brought the total number of curricula acted upon to 687, divided as follows:

Accredited unconditionally	433
Accredited for limited periods	82
Not accredited	172
Total	687

The complete list of accredited curricula appeared on page 526 of the December 1939 issue of ELECTRICAL ENGINEERING. A report on the annual meeting was published in the November 1939 issue of ELECTRICAL ENGINEERING, page 485.

REPRESENTATIVES

The Institute has continued its representation upon many joint committees and national bodies, with which it co-operates in a wide range of activities of interest and importance to engineers and others.

A list of representatives was published in the September 1939 issue of ELECTRICAL ENGINEERING and in the 1940 Year Book.

FINANCE COMMITTEE

The preparation of the annual budget is one of the major duties of the finance committee. The budget for the current year (beginning October 1) has some interesting features.

While the European War results in appreciable loss in revenue to the Institute, the steady growth in membership is expected to offset this influence, and it is anticipated that the revenues for the year will be substantially the same as for last year. By careful attention to economy in some items and by estimating closely the necessary expenses it has been possible in the current budget to provide for carrying on the activities of last year and for the expansion of these activities in some respects. Provision was made for about a 10 per cent increase in the Institute publications and for the addition to the headquarter's staff of one engineer whose time is largely devoted to standards work. The allowance for traveling expenses for delegates to Institute meetings and to District conferences was made more nearly adequate. An item of especial interest is the establishment of a pension reserve fund by the initial payment into this fund of $5,000 as a part of the current year's expenses. This is done as a first step toward the eventual establishment of a pension system for superannuated employees.

Under advice of investment counsel, the investments representing the reserve funds of the Institute are for the present being kept in fluid condition, cash and short-term bonds representing about one-half of the total.

Haskins and Sells, certified public accountants, have audited the books, and their report follows.

APPRECIATION

The board of directors again expresses to the national committees and the District, Section, and Branch officers its sincere thanks for their effective conduct of the activities in these important divisions. Their leadership has continued to produce a high degree of enthusiasm and constructive accomplishment. The board of directors also deeply appreciates the generous interest and support which the members have accorded its efforts on their behalf.

Respectfully submitted for the board of directors.

H. H. HENLINE,
National Secretary

May 24, 1940

HASKINS & SELLS
CERTIFIED PUBLIC ACCOUNTANTS

22 EAST 40TH STREET
NEW YORK

May 16, 1940

American Institute of Electrical Engineers,
33 West 39th Street, New York.

Dear Sirs:

We have made an examination of your balance sheet as of April 30, 1940, and of your recorded cash receipts and disbursements for the year ended that date. Our examination consisted of a review of the system of internal control and the accounting procedures of the Institute and examination or tests of its accounting records and other supporting evidence by methods and to the extent we deemed appropriate. We present the following:

Balance Sheet, April 30, 1940 (Exhibit A).
Property and Restricted Funds Securities, Less Reserve for Securities of Doubtful Value (Schedule 1).

Statement of Recorded Cash Receipts and Disbursements of General Fund for the Year Ended April 30, 1940 (Exhibit B).

Statement of Recorded Cash Receipts and Disbursements of Property and Restricted Funds for the Year Ended April 30, 1940 (Exhibit C).

In accordance with the terms of our engagement, members and other debtors, except certain advertisers, were not requested to confirm to us the amounts receivable from them at April 30, 1940. In accordance with the usual practice of the Institute, no provision has been made for dues which may prove to be uncollectible.

In our opinion, subject to the comments in the next preceding paragraph, the accompanying Exhibit A fairly presents your financial condition at April 30, 1940, and the accompanying Exhibits B and C fairly present your recorded cash receipts and your disbursements of funds, as indicated, for the year ended that date.

Yours truly,

HASKINS & SELLS

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Balance Sheet, April 30, 1940

Exhibit A

ASSETS			LIABILITIES		
Property Fund Assets:			**Property Fund Reserve**		$553,405.23
One-fourth interest in the total net assets of United Engineering Trustees, Inc., exclusive of Trust Funds	$498,448.48		**Restricted Fund Reserves:**		
Equipment:			Reserve Capital Fund	$221,074.78	
Library—volumes and fixtures	37,296.37		Life Membership Fund	8,772.17	
Office furniture and fixtures (less reserve for depreciation, $30,091.16)	4,973.26		International Electrical Congress of St. Louis Library Fund	5,324.28	
Works of art, etc.	3,001.35		Lamme Medal Fund	4,364.00	
Securities—at cost (market quotation value, $6,505.45)—Schedule 1	6,355.45		Mailloux Fund	1,028.83	
Cash (see Exhibit C)	3,330.32		Total restricted fund reserves		240,564.06
Total property fund assets		$553,405.23	Current Liabilities—Accounts payable		11,396.55
Restricted Fund Assets:			Pension Fund Reserve		5,000.00
Securities—at cost, less reserve for securities of doubtful value (market quotation value, $177,352.94)—Schedule 1	$190,237.27		**Deferred Income:**		
Cash (see Exhibit C)	50,256.80		Dues received in advance	$ 4,782.92	
Accrued interest receivable	69.99		Entrance fees and dues advanced by applicants for memberships	602.35	
Total restricted fund assets		240,564.06	Deferred credits for other unallocated receipts	396.39	
Current Assets:			Subscriptions for TRANSACTIONS received in advance	25.00	
Cash (see Exhibit B)	$ 32,156.58		Reserve for prepaid subscriptions for ELECTRICAL ENGINEERING	7,400.00	
Accounts receivable:			Total deferred income		13,206.66
Members—for dues	19,921.28		Surplus		40,867.05
Advertisers	518.40				
Miscellaneous	3,596.94				
Accrued interest on investments	1,588.72				
Inventories:					
TRANSACTIONS, etc.	2,040.50				
Text and cover paper	5,746.61				
Work in process (May issue of ELECTRICAL ENGINEERING)	3,887.76				
Badges	1,013.47				
Total current assets		70,470.26			
Total		$864,439.55	**Total**		$864,439.55

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Statement of Recorded Cash Receipts and Disbursements of General Fund for the Year Ended April 30, 1940

Exhibit B

Cash on Deposit With The National City Bank of New York, May 1, 1939		$ 61,988.30
Receipts:		
Dues (including $89,982.00 allocated to ELECTRICAL ENGINEERING subscriptions)	$200,311.85	
Advertising	31,430.83	
TRANSACTIONS subscriptions	6,987.56	
ELECTRICAL ENGINEERING subscriptions	10,466.04	
Miscellaneous publications (preprints, standards, TRANSACTIONS index, etc.)	13,470.17	
Students fees	13,621.25	
Entrance fees	7,020.54	
Membership badges	1,753.25	
Transfer fees	1,060.00	
Interest on investments, less purchased interest	6,778.17	
Miscellaneous	15.16	
Total receipts		292,914.82
Total		$354,903.12
Disbursements:		
Publications expense:		
ELECTRICAL ENGINEERING	$ 81,689.94	
TRANSACTIONS	11,209.62	
YEAR BOOK	6,314.46	
Miscellaneous publications (preprints, standards, TRANSACTIONS index, etc.)	16,194.55	
Institute meetings	13,468.22	
Institute Sections	41,832.11	
Institute Branches	3,446.16	
Edison Medal committee	176.86	
Finance committee	600.00	
Headquarters committee	208.60	
Membership committee	7,738.91	
Standards committee	5,888.71	
Technical committee	223.62	
Traveling expenses:		
Geographical Districts:		
Executive committees	2,946.01	
Vice-presidents	556.80	
Forward	$192,494.57	$354,903.12
Total—(Forward)		$354,903.12
Disbursements—(Forward)	$192,494.57	
Traveling expenses—(Continued):		
Branch counselors and chairmen	7,823.75	
President's appropriation	403.05	
Board of directors	7,476.38	
National nominating committee	953.88	
Administrative expenses	46,910.84	
Geographical Districts—best paper prizes	165.50	
Initial paper prizes	25.00	
Institute prizes	227.21	
American Engineering Council	7,741.66	
American Standards Association	1,500.00	
United Engineering Trustees, Inc.:		
Building assessment	10,984.80	
Library assessment	9,811.52	
Engineering Societies Employment Service	1,380.44	
Engineers' Council for Professional Development	1,275.00	
Engineering Foundation Projects:		
Insulating oils and cable saturants	250.00	
Welding research	250.00	
Research on impregnated paper insulation	250.00	
National Fire Protection Association—dues	60.00	
United States Committee of International Commission on Illumination	300.00	
Membership badges	1,687.36	
Legal services	250.00	
Hoover Medal	175.55	
John Fritz Medal	100.00	
Lamme Medal	30.57	
Model registration law	187.53	
Transfer to reserve capital fund	30,000.00	
Miscellaneous	31.93	
Total disbursements		322,746.54
Cash on Deposit With The National City Bank of New York, April 30, 1940		$ 32,156.58

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Statement of Recorded Cash Receipts and Disbursements of Property and Restricted Funds for the Year Ended April 30, 1940

Exhibit C

	Restricted Funds						
	Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Mailloux Fund	Total Restricted Funds	Property Fund (Equipment Replacements)
Cash on Deposit With East River Savings Bank and The National City Bank of New York, May 1, 1939	$10,543.27	$3,841.26	$1,187.54	$148.73	$ 17.73	$15,738.53	$ 32.83
Receipts:							
Interest on bonds and dividends on stocks		$ 250.00	$ 207.39	$ 64.00	$ 45.00	$ 566.39	
Interest on bank balance		67.79				67.79	
Proceeds from sale and redemption of securities	$32,002.99		3,926.69		1,000.00	36,929.68	$8,697.49
Transfer from general fund	30,000.00					30,000.00	
Total receipts	$62,002.99	$ 317.79	$4,134.08	$ 64.00	$1,045.00	$67,563.86	$8,697.49
Total	$72,546.26	$4,159.05	$5,321.62	$212.73	$1,062.73	$83,302.39	$8,730.32
Disbursements:							
Annual withdrawal authorized in by-laws		$ 713.96				$ 713.96	
Gold and bronze replicas of Lamme Medal and certificate				$188.73		188.73	
Purchase of securities	$27,635.00		$4,437.50			32,072.50	$5,400.00
All other disbursements			26.50	10.00	$ 33.90	70.40	
Total disbursements	$27,635.00	$ 713.96	$4,464.00	$198.73	$ 33.90	$33,045.59	$5,400.00
Balance on Deposit With The National City Bank of New York and Various Savings Banks, April 30, 1940	$44,911.26	$3,445.09	$ 857.62	$ 14.00	$1,028.83	$50,256.80	$3,330.32

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Property and Restricted Funds Securities, Less Reserve for Securities of Doubtful Value, April 30, 1940

Schedule 1

		Restricted Funds					
	Principal Amount of Bonds or Number of Shares of Stock	Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Total Restricted Funds	Property Fund (Equipment Replacements)
Railroad Bonds:							
Alleghany Corporation 20-year collateral trust convertible 5%, due 1949	$15,000.00	$ 10,627.50				$ 10,627.50	
Baltimore & Ohio Railroad Company 6% refunding and general mortgage series C, due 1995 (stamped)	12,000.00	8,940.00			$4,330.00	13,270.00	
Central of Georgia Railway Company 5% consolidated mortgage, due 1945	3,000.00	1,477.50				1,477.50	
Chicago & Erie Railroad Company 5% first mortgage, due 1982	1,000.00	1,105.00				1,105.00	
Chicago & Northwestern Railway Company 6½%, due March 1, 1936	9,000.00	7,202.50				7,202.50	
Florida East Coast Railway Company 5% first and refunding mortgage series A, due 1974 (certificates of deposit)	10,000.00	9,818.75				9,818.75	
New York Central Railroad Company 5% refunding and improvement mortgage series C, due 2013	6,000.00	5,742.50				5,742.50	
Northern Pacific Railway Company 6% refunding and improvement mortgage series B, due 2047	10,000.00	10,962.50				10,962.50	
St. Louis-San Francisco Railway Company 5% prior lien mortgage series B, due 1950 (certificates of deposit)	6,000.00	5,497.50				5,497.50	
Texas and Pacific Railway Company general and refunding series B 5%, due 1977	5,000.00		$5,306.25			5,306.25	
Western Pacific Railroad Company 5% series A, due 1946 (stamped)	15,000.00	7,225.00				7,225.00	
Total railroad bonds		$ 68,598.75	$5,306.25		$4,330.00	$ 78,235.00	
Public Utility Bonds:							
Edison Electric Illuminating Company of Boston 3½% first mortgage series A, due 1965	2,000.00			$2,222.50		$ 2,222.50	
Illinois Bell Telephone Company 3½% first and refunding mortgage series B, due 1970	2,000.00			2,215.00		2,215.00	
New York & Queens Electric Light & Power Company 3½% first and consolidated mortgage, due 1965	10,000.00	$ 11,000.00				11,000.00	
Total public utility bonds		$ 11,000.00		$4,437.50		$ 15,437.50	
FORWARD		$ 79,598.75	$5,306.25	$4,437.50	$4,330.00	$ 93,672.50	

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

Property and Restricted Funds Securities, Less Reserve for Securities of Doubtful Value, April 30, 1940

Schedule 1 (Concluded)

	Principa Amount of Bonds or Number of Shares of Stock	Restricted Funds: Reserve Capital Fund	Life Membership Fund	International Electrical Congress of St. Louis Library Fund	Lamme Medal Fund	Total Restricted Funds	Property Fund (Equipment Replacements)
FORWARD		$ 79,598.75	$5,306.25	$4,437.50	$4,330.00	$ 93,672.50	
Industrial and Miscellaneous Bonds, Etc.:							
Fidelity Union Title and Mortgage Guaranty Company first mortgage certificates (on property 75–79 Prospect Street, East Orange, N. J.) 4%, due 1944	$14,329.77	$ 13,374.32				$ 13,374.32	$ 955.45
General Motors Acceptance Corporation 3¼%, due 1951	7,000.00	7,140.00				7,140.00	
United States Steel Corporation debentures 3¼%, due 1948	8,000.00	8,240.00				8,240.00	
Total industrial and miscellaneous bonds, etc.		$ 28,754.32				$ 28,754.32	$ 955.45
United States Government Bonds and Notes:							
Federal Farm Mortgage 3%, due 1949/44	12,000.00	$ 12,405.00				$ 12,405.00	
Treasury Bonds 3¼%, due 1941	10,000.00	10,650.00				10,650.00	
Treasury Bonds 2¾%, due 1947/45	10,000.00	10,409.38				10,409.38	
Treasury Bonds 3¼%, due 1943/40	10,000.00	10,537.50				10,537.50	
Treasury Bonds 3¼%, due 1943/41	10,000.00	10,681.25				10,681.25	
Treasury Notes 2% series B, due September 15, 1942	21,000.00	21,756.57				21,756.57	
Treasury Savings Bonds series D, due July 1, 1949	10,000.00	2,100.00				2,100.00	$5,400.00
Treasury Savings Bonds series D, due January 1, 1950	10,000.00	7,500.00				7,500.00	
Total United States Government bonds and notes		$ 86,039.70				$ 86,039.70	$5,400.00
Capital Stocks:							
Commonwealth Edison Company	48 shares	$ 2,892.00				$ 2,892.00	
Commercial Investment Trust Corporation 4¼% preferred, series of 1935	100 "	10,100.00				10,100.00	
International Match Realization Co., Ltd. voting trust certificates for capital shares of International Match Corporation	6 "	2,154.15				2,154.15	
Total capital stocks		$ 15,146.15				$ 15,146.15	
Total		$209,538.92	$5,306.25	$4,437.50	$4,330.00	$223,612.67	$6,355.45
Less Reserve for Securities of Doubtful Value:							
Central of Georgia Railway Company 5% consolidated mortgage, due 1945	$ 3,000.00	$ 1,477.50				$ 1,477.50	
Chicago & Northwestern Railway Company 6¼%, due March 1, 1936	9,000.00	7,202.50				7,202.50	
Florida East Coast Railway Company 5% first and refunding mortgage series A, due 1974	10,000.00	9,818.75				9,818.75	
International Match Realization Co., Ltd. voting trust certificates for capital shares of International Match Corporation	6 shares	2,154.15				2,154.15	
St. Louis-San Francisco Railway Company 5% prior lien mortgage series B, due 1950	$ 6,000.00	5,497.50				5,497.50	
Western Pacific Railroad Company 5% series A, due 1946 (stamped)	15,000.00	7,225.00				7,225.00	
Total reserve for securities of doubtful value		$ 33,375.40				$ 33,375.40	
Total Property Fund Securities							$6,355.45
Total Restricted Fund Securities, Less Reserve		$176,163.52	$5,306.25	$4,437.50	$4,330.00	$190,237.27	

Board of Directors Meets

At its regular meeting at Institute headquarters, May 24, 1940, the AIEE board of directors approved the establishment of a technical committee on domestic and commercial applications, with the understanding that the statement of scope of the new committee will be prepared in co-operation with the technical program committee and will include the subject of applications to refrigeration.

Upon recommendation of the committee on planning and co-ordination, the board voted to change the status of the committee on research from that of a technical committee to that of a general committee. Effects of the change will be to eliminate some duplication of the activities of the other technical committees, which are in a measure concerned with research in their respective fields; to add functions intended to stimulate research activities along lines pertaining to the Institute; and to give research in electrical engineering a somewhat more general and representative status than it has had.

Recommendation of the committee on planning and co-ordination that the technical committees be encouraged to prepare special material in their respective fields for publication on a self-supporting basis was approved. The Lightning Reference Book, published under the auspices of the committee on power transmission and distribution, was mentioned as an outstanding example.

Referred to the incoming board were the report of the special committee on radio talks on electrical-engineering subjects, to be presented at the August meeting, and a progress report of the special committee on posthumous honors, recommendations of which were recommended for favorable action, provided the necessary financial support is available.

The board adopted a statement of "Institute Policy Concerning Standardization Activities" contained in a report on "AIEE and Standardization", made by F. Malcolm Farmer in accordance with action of the executive committee as a result of a request for a clarification of the relationship between the AIEE and the American Standards Association. The statement appears on page 306. Approval was given for publication of revisions of AIEE Standards No. 1,

"General Principles Upon Which Temperature Limits Are Based in the Rating of Electrical Machinery and Apparatus", and No. 22, "Air Switches and Bus Supports".

Applications to the Engineering Foundation for continued support of three research projects during the year beginning October 1, 1940, were reported and confirmed. These are:

Project 66, Stability of Impregnated-Paper Insulation

Project 74, Insulating Oils and Cable Saturants

Project 62, Welding Research

The board authorized a Southern District meeting to be held in New Orleans in the fall of 1941, upon request of the District executive committee.

Establishment of a Student Branch at Norwich University, Northfield, Vermont, was authorized, upon recommendation of the committee on Student Branches.

A new style of Institute badge, a small key charm, was added to the list of Institute badges, and a revised price list of badges approved.

Amendments to Institute bylaws were adopted as follows:

Section 65, third paragraph amended by substitution of the word "additional" for the word "auxiliary" to read:

"The president or the board of directors may appoint additional members to any committee."

Section 68, first paragraph amended by addition of the word "appointed" to read:

"The technical program committee shall consist of nine appointed members, and the chairman of each technical committee, the chairman of the committee on planning and co-ordination, and the chairman of the committee on safety, ex officio."

Section 84, first sentence amended by addition of the word "appointed" to read:

"The committee on Student Branches shall consist of five appointed members and the counselor of each Branch, ex officio, and shall have general supervision and management of the Student Branches of the Institute."

The board took the following action on appointments:

Reappointed H. H. Henline national secretary for the year beginning August 1, 1940.

Nominated W. I. Slichter to represent AIEE as a member of the Engineering Foundation board for the four-year term beginning in October 1940.

Appointed John C. Parker AIEE representative on American Engineering Council, succeeding C. E. Stephens, whose resignation was accepted.

Empowered the president to appoint a representative on the Washington Award commission for the two-year term beginning June 1, 1940.

Confirmed committee of tellers appointed by president for 1940 election, as follows: E. C. Plant, *chairman*, H. H. Duehne, E. P. Ellis, O. T. Laube, J. E. Loehr, F. T. Meyer, S. H. Thomas.

Appointed representatives recommended by standards committee, as follows:

Wray Dudley, Fred Schnure, W. E. Crawford, AIEE delegation, sectional committee on welding, C52.

W. B. Kouwenhoven, sectional committee on dry cells and batteries, C18, succeeding E. D. Doyle.

Edward Bennett, chairman of AIEE delegation, sectional committee on electric and magnetic magnitudes and units, C61, succeeding A. E. Kennelly, deceased.

Requested the committee on economic status of the engineer to appoint four AIEE representatives to participate in a national conference on engineering positions, in response to an invitation from the American Society of Civil Engineers.

Other action by the board included:

Annual report of the national treasurer for the fiscal year ending April 30, 1940, approved.

Draft of annual report of board of directors, submitted by the national secretary, approved for presentation at the annual meeting of the Institute at Swampscott, Mass., June 24, 1940, subject to suggestions for changes presented by members of the board prior to printing date.

Minutes of meetings of board of directors, January 23, 1940, and of executive committee, March 8, 1940, approved.

Executive committee action, as of April 12, 1940, confirmed, as follows: 2 applicants transferred to grade of Fellow; 15 transferred and 17 elected to grade of Member; 538 elected to grade of Associate; 96 Students enrolled.

Reports of board of examiners' meetings, March 14, April 18, and May 16, 1940, approved; action on recommendations as follows: 2 applicants re-elected to grade of Fellow; 12 transferred and 23 elected to grade of Member; 483 applicants elected to grade of Associate; 261 Students enrolled.

Finance committee report: expenditures in March, $25,318.69; April, $20,829.23; May, $32,959.23; approved.

Those present were:

President—F. Malcolm Farmer, New York, N. Y.

Past President—John C. Parker, New York, N. Y.

Vice-Presidents—T. F. Barton, New York, N. Y.; C. L. Dawes, Cambridge, Mass.; F. R. Maxwell, Jr., University, Ala.; C. T. Sinclair, Pittsburgh, Pa.; J. M. Thomson, Toronto, Can.

Directors—C. R. Beardsley, H. S. Osborne, New York, N. Y.; Mark Eldredge, Memphis, Tenn.; R. E. Hellmund, C. A. Powel, Pittsburgh, Pa.; L. R. Mapes, Chicago, Ill.; K. B. McEachron, Pittsfield, Mass.; D. C. Prince, Schenectady, N. Y.; R. W. Sorensen, Pasadena, Calif.

National Treasurer—W. I. Slichter, New York, N. Y.

National Secretary—H. H. Henline, New York, N. Y.

New Key Charm Badge Available

A new article of Institute jewelry is the key charm AIEE badge approved by the board of directors at its meeting, May 24, 1940. The new badge, shown full size in the accompanying illustration, is now available on order from AIEE headquarters, 33 West 39th Street, New York, N. Y.; price $4.50. The price of the standard watch-charm AIEE emblem recently has been reduced from $5.00 to $4.50 also.

Additions to List of Members for Life

Membership for life is granted by the AIEE to members who either have paid annual dues for 35 years, or have reached the age of 70 and have paid dues for 30 years. A list of those who have become members for life during the preceding year is published annually in ELECTRICAL ENGINEERING. The following are the Institute members who have reached member-for-life status since publication of the last previous list in the July 1939 issue.

E. W. Ackland
John R. Anderson
D. F. Atkins
P. A. Baker
E. H. Bangs
H. Barker
T. W. Behan
B. J. G. S. Bergman
V. Boyd
W. C. Boyrer
A. M. Buck
H. D. Carpenter
G. F. Chellis
W. G. Clark
W. N. Clark
B. H. Clingerman
A. Coggeshall
Frank Conrad
J. S. G. Cooper
W. J. Crumpton
J. C. Damon
R. H. Dillon
R. T. Durran
H. C. Eddy
W. Elsdon-Dew
A. F. Enstrom
C. J. Fechheimer
T. Fitzgerald
C. W. Fletcher
H. C. Ford
D. L. Galusha
C. M. Garland
E. F. Gehrkens
C. P. Goepel
F. F. Grevatt
J. W. Hancock
F. C. Hanker
J. L. Hansen
H. V. Hayes
J. C. Hays
N. Hayward
R. E. Hellmund
J. S. Henderson
W. S. Higgins
L. L. Holladay
C. W. Humphrey
F. W. Hurlbert
C. M. Jansky
J. P. Jollyman
M. G. Kennedy
C. G. Kilbourne
E. D. King
C. T. Knipp
R. R. Lawrence
S. J. Lisberger
D. E. Manson
S. W. Mauger
G. K. McDougall
J. C. Mock
E. W. Muller
E. R. Northmore
I. H. Osborne
A. J. Pahl
H. R. Palmer
H. Parodi
W. M. Piatt
L. J. Pierce
A. Pirelli
N. Platt
H. J. Podlesak
W. G. T. Pope
H. A. Putnam
L. O. Ripley
F. A. Rogers
W. B. Sanford
T. G. Seidell
J. B. Sirrine
H. L. Smith
W. J. Smith
H. Clyde Snook
S. A. Spalding
C. W. Speirs
W. B. Spellmire
J. S. Stone
T. P. Strickland
J. O. Taylor
W. A. Thomas
A. N. Topping
C. E. Torrey
H. M. Van Gelder
H. L. Van Valkenburg
Theodore Varney
J. C. Vincent
H. C. Walter
K. W. Waterson
W. G. H. Whitaker
G. Wittig
Fay Woodmansee
H. W. Young

Future AIEE Meetings

Pacific Coast Convention
Los Angeles, Calif., August 27–30, 1940

Middle Eastern District Meeting
Cincinnati, Ohio, October 9–11, 1940

Winter Convention
Philadelphia, Pa., January 27–31, 1941

District • • • •

Seven Districts Announce Prize Awards for Papers

District prizes for AIEE papers have been announced by seven Districts to date. The awards are for papers presented during 1939, except Branch papers, which must have been presented during the academic year ending June 30, 1939, according to the revised rules adopted in 1937 and amended January 23, 1940.

District 1

Prize for best paper was awarded to D. S. Snell (A'24) for his paper "The Hydrogen-Cooled Turbine Generator," presented at the North Eastern District meeting, Springfield, Mass., May 3, 1939. Honorable mention was made of the paper "The Rectifier Calculus" by W. Melvin Goodhue (A'31) presented at the North Eastern District meeting, Springfield, Mass., May 5, 1939.

Prize for Branch paper was awarded jointly to W. N. Brown, Jr. (Enrolled Student) and E. W. Sheridan (Enrolled Student) for their paper "Frequency-Selective Feedback for Improvement of Acoustical Response of an Audio-Frequency Sound System" and to E. C. Dench (Enrolled Student) for his paper "The 'Glo-Relay,' a New Method of Initiating Vapor Discharges," presented at the North Eastern District meeting, Springfield, Mass., May 5, 1939.

District 3

Prize for Branch paper was awarded to Paul J. Reifschneider (Enrolled Student) for his paper "An Electronic Voltage Regulator for an Alternator," presented at a meeting of the Polytechnic Institute of Brooklyn Branch, Brooklyn, N. Y., April 20, 1939.

District 6

Prize for Branch paper was awarded to Jay W. Forrester for his paper "Electrostatic Dust Precipitators," presented at the annual student conference of District 6, Laramie, Wyo., April 21–22, 1939.

District 7

Prize for Branch paper was awarded to Robert B. Bonney (Enrolled Student) for his paper "Directional Antennas for Broadcast Stations," presented at the conference on student activities, South West District meeting, Houston, Tex., April 19, 1939.

Prize for graduate paper was awarded to Nejat Atsan (membership application pending) for his paper "A Method of Line-Voltage Control," presented at the conference on student activities, South West District meeting, Houston, Tex., April 19, 1939.

District 8

Prize for Branch paper was awarded to Thomas E. Curtis (A'40) for his paper "Compound Frequency Control of Power Systems," presented at summer and Pacific Coast convention, San Francisco, Calif., June 29, 1939.

Prize for graduate paper was awarded to Arthur E. Harrison (A'39) for his paper "Ionization Time of Thyratrons," presented at summer and Pacific Coast convention, San Francisco, Calif., June 27, 1939.

District 9

Prize for best paper and prize for initial paper were awarded to Herbert N. Steen (A'31) for his paper "A Three-Element Cathode-Ray Oscillograph," presented at a meeting of the Seattle Section, December 19, 1939.

Prize for Branch paper was awarded to Opal Cummins (membership application pending) and Willice Groves (A'37) for their paper "Water-Cooled Radio Frequency Amplifier With Grounded Anodes," presented at a joint meeting of the Utah Section and University of Utah Branch, Salt Lake City, May 22, 1939.

District 10

Prize for best paper was awarded to Hubert R. Sills (A'24, M'31) for his paper "Vertical Shaft Generators," presented at a meeting of the Toronto Section, January 27, 1939.

Prize for initial paper was awarded to Archie M. Doyle (A'37) for his paper "Lightning Protection for Power Transmission Systems," presented at a meeting of the Toronto Section, January 13, 1939.

District 8 Executive Committee

The executive committee of the Pacific District (8) met May 14, 1940, at Los Angeles, Calif., and discussed matters of routine business. Arrangements for the program of the conference on student activities, planned to be held at Los Angeles during the forthcoming Pacific Coast convention, were discussed, also the possibility of holding the 1942 Pacific Coast convention at San Diego, and other matters relating to planning conventions.

Commended as worthy of consideration by other Sections were the Los Angeles Section's practice of encouraging members to entertain Enrolled Students regularly at dinner meetings; and the San Francisco Section's policies of making new members guests of the membership committee at the first dinner meeting following election, and of encouraging continued interest by graduating Students, through letters sent well in advance of graduation, which encourage transfer to Associate grade, offer to notify the Student of meetings, and enclose a prepaid postcard for reply.

Branch • • • •

District 1 Convention at Rensselaer

The annual convention of Student Branches of the Northeastern District (1) was held at Rensselaer Polytechnic Institute, Troy, N. Y., May 3–4, 1940. Features of the convention were three technical sessions, inspection of the transformer plant and plastics division of the General Electric Company at Pittsfield, Mass., conference of counselors and chairmen, and a banquet at which District Vice-President C. L. Dawes was toastmaster and Doctor W. O. Hotchkiss, president of Rensselaer, AIEE President F. Malcolm Farmer, and E. S. Lee, nominee for vice-president of District 1, were speakers.

At the technical sessions on May 4, the following student papers were presented:

Graduate-student papers session: E. C. Dench, Massachusetts Institute of Technology, chairman

RELUCTANCE-MOTOR CHARACTERSITICS, H. deFritsch, Harvard University

A NEW CONCEPT IN COMMUNICATION, W. N. Brown, Jr., Massachusetts Institute of Technology

SILVER-GRAPHITE BRUSHES, H. M. Parshall, Rensselaer Polytechnic Institute

A SHARP CUTOFF LIMITOR, J. J. Hagopian, Worcester Polytechnic Institute

MAGNETOSTRICTION OSCILLATORS, Herbert Krauss, Yale University

Undergraduate papers session: measurements and general, S. K. Brown, Cornell University, chairman

MEASUREMENT OF QUADRATURE-AXIS REACTANCE, H. T. Marcy, Massachusetts Institute of Technology

ANALYSIS OF IMPULSE VOLTAGES BY LICHTENBERG FIGURES, Nickos Petrou and Frank Rosenkrans, Northeastern University

THE SENSITIVITY OF BRIDGES, C. A. Lister, Tufts College

A STUDY OF FLUORESCENT LAMPS, T. C. Muchmore, Cornell University

OSCILLOGRAPHIC DETERMINATION OF FREQUENCY-RESPONSE CURVES, R. M. Sills, Yale University

CIRCUIT FOR AN ELECTRONIC INTEGRATOR, J. H. Arthur, Rensselaer Polytechnic Institute

"PSYCHOGALVANOMETER," J. L. Raesler, Syracuse University

ELECTROMAGNETIC SYSTEM FOR AIRPLANE BLIND-LANDING, W. T. Gore and D. G. Howard, Worcester Polytechnic Institute

Undergraduate papers session: communication and electronics, W. A. Knoop, Rensselaer Polytechnic Institute, chairman

THE BROWN NETWORK, D. W. Borst, Brown University

WIDE-BAND TRANSMITTER, T. M. Ferrill, Jr., Massachusetts Institute of Technology

AN ULTRAHIGH-FREQUENCY TRANSMITTER FOR AMPLITUDE OR FREQUENCY MODULATION, Norman Caplan, Rensselaer Polytechnic Institute

WIRED WIRELESS INTERCOMMUNICATIONS, A. A. MacDonald, Yale University

LOUD-SPEAKER DIVIDER NETWORK, R. F. Scharmann, Worcester Polytechnic Institute

A REMOTE-CONTROL DIMMER, R. E. Armington, Tufts College

ELECTRIC AND MAGNETIC FOCUSING OF THE CYCLOTRON BEAM, D. B. Hoisington, Massachusetts Institute of Technology

ELECTRONIC CONTROL OF THYRATRONS, R. B. Russ, Yale University

Speaking prizes, presented at a luncheon on May 4, were as follows: graduate session—first prize, J. J. Hagopian; measurements session—first prize, Nickos Petrou and Frank Rosenkrans, second prize, W. T. Gore and D. G. Howard; communications session—first prize, T. M. Ferrill, Jr., second prize, Norman Caplan. The District 1 award for best Branch paper for 1938–39, awarded jointly to E. C. Dench for his paper "The 'Glo-Relay', a New Method of Initiating Vapor Charges", written at Worcester Polytechnic Institute, and to W. N. Brown, Jr., and E. W. Sheridan, Massachusetts Institute of Technology, for their paper "Frequency-Selective Feedback for Improvement of Acoustical Response of an Audio-Frequency System", was presented at the banquet on May 3.

At the conference of Branch counselors and chairmen on May 4, the following were elected to the District committee on student activities for 1940–41: E. A. Walker, Tufts College, chairman; A. G. Conrad, Yale University; G. S. Brown, Massachusetts Institute of Technology. E. M. Strong, Cornell University, retiring chairman, was designated as District 1 counselor delegate to the summer convention at Swampscott, Mass.

The report "The Status of the Graduate Student in AIEE Student Branch Activities", copies of which had been distributed, was discussed in detail, with special consideration given the problems created by lack of uniform practice among schools in distinguishing graduate and undergraduate status, and in terminating Enrolled Student status for graduate students employed by the school. The meeting voted to refer the report back to the committee for revision, correction, and reconsideration, all counselors being urged to submit written comments or criticisms. The meeting voted in favor of July 15 as a closing date for student papers, and expressed itself as favoring the use of a student page in ELECTRICAL ENGINEERING for publishing abstracts of student papers winning District prizes.

Conference of District 7 Branches

The 15 Branches in the South West District (7) held the annual Student Branch conference April 19–20, 1940, at Texas Technological College, Lubbock, Tex. Technical sessions were held on both days at which papers were presented for the annual graduate and undergraduate competitions. Titles and authors of the papers presented were not available at publication time.

Winners in the competitions were announced at a luncheon on April 20, at which District Vice-President F. C. Bolton was a speaker. They were as follows:

Undergraduate competition—first place, Leroy Evans and Raymond Glass, Texas Technological College; second place, Dale W. Whitaker and Richard B. Scott, University of Kansas; third place, Roger K. Ghormley, Kansas State College. Graduate competition—first place, Luther R. Johnson, Texas A. and M. College; second place, Edwin A. Goldberg, University of Texas.

Counselors and Branch chairmen and chairmen-elect held a breakfast meeting on April 20, after which student officers and counselors held separate business meetings. The chairmen's meeting agreed to present a slide rule to Chairman C. F. Barnard of the Texas Technological College Branch, in recognition of his work in organizing the conference; voted to make

reports on next year's plans early in the year and to distribute these to all Branch officers.

The business meeting of counselors voted to hold the 1941 student conference in connection with the South West District meeting since both are scheduled to be held in St. Louis, Mo. An invitation to hold the 1942 conference at the University of New Mexico, Albuquerque, was offered. J. S. Johnson, Missouri School of Mines and Metallurgy, Rollo, was elected chairman of the District committee on student activities for the coming year.

Methods of grading student papers were discussed at length. It was voted to have two groups of judges, one for graduate and one for undergraduate papers, in the future. The meeting later voted to have no formal judging or competition, but to require that papers be turned in two weeks before the date of the conference in order to be presented on the program, and to send two copies to each Branch. It was urged that more papers be submitted for national and District prize, in accordance with the suggestion of the AIEE committee on Student Branches.

After discussion of the desirability of a student page in ELECTRICAL ENGINEERING, the new chairman was requested to investigate methods of arranging for this space.

Joint Meeting at Stanford

The annual joint meeting of the three local Student Branches with the San Francisco Section was held at Stanford University, Calif., April 26, 1940. A demonstration of the 2,000,000-volt lightning generator at Ryan Laboratory and dinner at the Stanford Union preceded the meeting, which featured the annual competition for the student-paper prize presented by the San Francisco Section. The following papers were presented:

POWER SYSTEM CONTROL BY TELEMETERING, **Bernard Cassidy**, University of Santa Clara

TWO INSTRUMENTS TO INDICATE THE POLARITY OF HIGH-VOLTAGE SPARK DISCHARGES, **O. J. M. Smith**, Stanford University

SPEED-TORQUE CURVES OF MOTORS BY ACCELERATION METHODS, **C. N. Williamson**, University of California

The prize, one year's dues as an Associate in the Institute, was awarded to O. J. M. Smith. The contest was preceded by a talk by Vice-President H. W. Hitchcock of District 8, and followed by presentation of the sound film of Doctor Charles F. Scott being shown by many Branches this year in commemoration of their founder's 75th birthday.

Standards • • •

Institute Policy Concerning Standardization Activities

Acting on the suggestion of President Farmer, the following statement of policy concerning Institute standardization activities has been prepared for the information of the membership. It is intended to present a clear picture of scope and character of Institute activities, and their relationship to the work of the American Standards Association.

The statement has been discussed by the standards committee and approved at its meeting on March 26. The board of directors indicated its approval at its meeting of May 24.

Standardization in the electrical engineering field is an important element in the advancement of the art—one of the stated objectives of the Institute. Therefore the Institute should take a prominent and, where appropriate, leading part in all standardization activities with which electrical engineering is concerned.

DEVELOPMENT OF STANDARDS

With respect to the development of standards, the following is the general policy of the Institute, it being understood that certain situations may develop which will require departure therefrom:

1. The development of a standardization project idea anywhere in the Institute organization is encouraged. The proposal should, however, be referred to the standards committee for consideration and action.

2. The standards committee will then review the proposal and determine whether or not the idea should be taken up as an Institute project. If the decision is affirmative, the standards committee will decide whether to:

(*a*) submit at once a request to the American Standards Association that the proposed project be undertaken by the ASA under sectional committee procedure with the AIEE as either sole or joint sponsor, or

(*b*) develop the proposed standard solely as an AIEE project without reference to ASA or any other body, or

(*c*) carry on, solely as a standards committee activity, the preliminary developmental, research, or other strictly technical "spade" work that may be required, with the expectation that ultimately ASA approval will be asked under the existing standards method, the general acceptance method, or by the sectional committee method, whichever seems most appropriate.

PUBLICATION OF STANDARDS

The following is the general policy of the Institute with respect to publication of standards:

1. A standard shall be designated an AIEE Standard in the official list of AIEE Standards whenever it is approved by the Institute irrespective of the auspices under which it was developed. This designation would therefore apply to:

(*a*) standards developed solely by and within the Institute, which have not been submitted to ASA for approval by that body. They would carry an AIEE number only.

(*b*) standards developed as in group *a*, but approved by ASA. They would carry both AIEE and ASA numbers (which may be identical).

(*c*) standards developed under ASA sectional committee procedure when approved by the Institute and of course also by ASA. They would carry both AIEE and ASA numbers (which may be identical).

(*d*) standards developed under any other auspices which the Institute may wish to approve as AIEE Standards. They would carry the AIEE number.

2. The Institute will publish all standards in groups *a* and *b*. The Institute also will publish the standards included in group *c* where the Institute is sole sponsor, or in the case of joint sponsorship, where it is so arranged with the joint sponsor or sponsors. All standards published by the Institute are to be in a uniform style conforming as far as practicable with ASA "Proposed Form and Arrangement of Published Standard," and with uniform title pages.

3. The term "AIEE Standard," prominently printed on the title page of many Institute standards, is to be dropped and instead incorporated (prominently) in the serial number designation, thus, "AIEE Standard No. 45, December, 1938."

4. Drafts or reports of *proposed* standards should be published with a title-page format which clearly distinguishes them from standards. In general, in order to make this distinction more emphatic, such documents preferably should be produced by the offset process rather than by printing.

Personal • • •

N. H. Coit (A'19, M'27) formerly vice-president and general manager of the South Carolina Electric and Gas Company, Columbia, has been made president and general manager. Born in Indianapolis, Ind., December 9, 1894, he received the degree of bachelor of science in electrical engineering from the University of Colorado in 1917. He was employed by the Mountain States Telephone and Telegraph Company in Denver, Colo., and Salt Lake City, Utah, in 1917–18, and from 1918 to 1923 was superintendent of the Auburn, Nebr., plant of the Western Public Service Company. He became associated with the General Gas and Electric Corporation in 1923 as assistant commercial manager of the Pennsylvania Edison Company, with headquarters at Easton, Pa. The following year he was transferred to Orlando, Fla., as general manager of the Florida Public Service Company. In 1929 he was made general manager of the Broad River Power Company, now South Carolina Electric and Gas Company, and in 1930 became vice-president. He was appointed vice-president also of the Lexington Water Power Company, of which he is now president.

C. M. Jansky (A'06, F'32) has retired as professor of electrical engineering, University of Wisconsin, Madison. He was born March 15, 1870, at Bloom, Wis., and received the degree of bachelor of arts from Valparaiso University in 1893, and that of bachelor of science in electrical engineering from the University of Michigan in 1904. After ten years of public-school teaching at Ausable, Mich., he became an assistant in physics at the University of Michigan, Ann Arbor, while securing his second degree. He was a research assistant at the National Bureau of Standards, Washington, D. C., 1904–05, and in 1905 became professor of physics and electrical engineering at the University of Oklahoma, Norman, where he headed the engineering department. He went to the University of Wisconsin as assistant professor in 1908, later becoming associate professor and full professor. He is the author of several books and a number of technical articles, and is also a member of Sigma Xi, the American Association for the Advancement of Science, the Society for the Promotion of Engineering Education, and the Society of Mathematicians and Physicists of Czechoslovakia.

F. J. Scudder (M'25) co-author with John N. Reynolds of the paper "Crossbar Dial Telephone Switching System" has received the 1939 AIEE national prize award for best paper in engineering practice. Born at

F. J. SCUDDER

W. C. JOHNSON

F. C. HOLTZ

Norwalk, Conn., June 2, 1884, and educated there, Mr. Scudder received his technical education through correspondence courses. He entered the employ of the New York (N. Y.) Telephone Company in 1905, on central office maintenance, becoming central office wire chief in 1908. In 1910 he was appointed equipment engineer and detailed to study semimechanical systems then under development by Western Electric Company. He was transferred to the technical staff of Western Electric in 1918, and when Bell Telephone Laboratories was formed continued on the technical staff of that organization. For some years he has been systems development engineer responsible for circuit development and economic studies relating especially to expansion of dial systems and for circuit design associated with the commercial application of such developments.

F. C. Holtz (A'16, M'25) has received the 1939 AIEE national prize award for best paper in theory and research for his paper on "The Anomalous Behavior of the Moving Systems of Single-Phase A-C Watt-Hour Meters at No Load". He was born at Wahoo, Nebr., May 6, 1888, and received the degree of bachelor of science in electrical engineering from the University of Nebraska in 1913. He spent the next three years with General Electric Company, Schenectady, N. Y., in the testing and consulting engineering departments, returning to the University of Nebraska, Lincoln, in 1916 as instructor in electrical engineering. Following army service during 1917–18, he became chief engineer of the Sangamo Electric Company, Springfield, Ill., later becoming vice-president. He has continued with the company in those capacities ever since.

W. C. Johnson (A'35) has received the 1939 AIEE national prize award for initial paper for his paper "Predetermination of Temperatures in Resistance Welds". Born January 6, 1913, at Weikert, Pa., he received the degree of bachelor of science in electrical engineering from Pennsylvania State College in 1934. Following graduation, he was employed by General Electric Company, Schenectady, N. Y., as a student engineer. After a year in the testing department he was transferred to the engineering department, where he continued until 1937, and during this period completed the three-year advanced course in engineering offered by the company. In 1937 he became an instructor in electrical engineering at Princeton University, Princeton, N. J., and recently was advanced to assistant professor. He is also a member of Tau Beta Pi, Eta Kappa Nu, and Sigma Xi.

E. C. Dench (Enrolled Student) Massachusetts Institute of Technology, Cambridge, has received the 1939 AIEE national prize award for Branch paper for his paper on "The 'Glo-Relay', a New Method of Initiating Vapor Discharges". He has also received the AIEE District 1 prize award for best Branch paper for 1938–39. Both prizes were awarded jointly for this paper and one by W. N. Brown, Jr., and E. W. Sheridan (Enrolled Students). Mr. Dench was born at East Orange, N. J., July 12, 1916, and received the degree of bachelor of science at Worcester Polytechnic Institute in 1939 and that of master of science at Massachusetts Institute of Technology in 1940. The prize-winning paper was written while he was a student at Worcester Institute, where he held a Westinghouse Memorial scholarship. During 1939–40 he held a Tau Beta Pi fellowship for graduate study at MIT. Before entering college and during several vacations he was employed at the Westinghouse Lamp Division, Bloomfield, N. J. He is also a member of Sigma Xi.

W. N. Brown, Jr. (Enrolled Student) Massachusetts Institute of Technology, Cambridge, co-author with E. W. Sheridan (Enrolled Student) of the paper "Frequency-Selective Feedback for Improvement of Acoustical Response of an Audio-Frequency Sound System", has received the 1939 AIEE national prize award for Branch paper. He has also received the AIEE District 1 prize award for best Branch paper for 1938–39. Both prizes were awarded jointly for this paper and one by E. C. Dench (Enrolled Student). Mr. Brown was born at Washington, D. C., November 16, 1917, and is studying electrical engineering in the five-year cooperative course at MIT, having had eight months of co-operative work at the General Electric Company. He has been vice-chairman of the MIT Student Branch and is also a member of Sigma Xi and a student member of the Institute of Radio Engineers.

E. W. Sheridan (Enrolled Student) Massachusetts Institute of Technology, Cambridge, co-author with W. N. Brown, Jr. (Enrolled Student) of the paper "Frequency-Selective Feedback for Improvement of Acoustical Response of an Audio-Frequency Sound System", has received the 1939 AIEE national prize award for Branch paper. He has also received the AIEE District 1 prize award for best Branch paper for 1938–39. Both prizes were awarded jointly for this paper and one by E. C. Dench (Enrolled Student). Mr. Sheridan was born April 25, 1917, at Malden, Mass., and is studying electrical engineering at Massachusetts Institute of Technology.

W. N. BROWN, JR.

E. W. SHERIDAN

E. C. DENCH

H. A. Affel (A'18, M'23) with co-author B. W. Kendall (M'18, F'29) has received honorable mention in the 1939 AIEE national prize award for best paper in engineering practice for their paper "A 12-Channel Carrier Telephone System for Open-Wire Lines". Born at Brooklyn, N. Y., August 4, 1893, Mr. Affel received the degree of bachelor of science at Massachusetts Institute of Technology in 1914. From 1914 to 1916 he was a research assistant in the electrical-engineering department at MIT, Cambridge, and in 1916 he went with the American Telephone and Telegraph Company, New York, N. Y. After three years in the engineering department, he was transferred to the department of development and research, and in 1934 he was transferred to Bell Telephone Laboratories, where he is at present assistant director of transmission development. He also received honorable mention for best paper in engineering practice in the AIEE national prize awards for 1934, and recently was honored by the National Association of Manufacturers as a "modern pioneer".

B. W. Kendall (M'18, F'29) with co-author H. A. Affel (A'18, M'23) has received honorable mention in the 1939 AIEE national prize award for best paper in engineering practice, for their paper "A 12-Channel Carrier Telephone System for Open-Wire Lines". Mr. Kendall was born November 1, 1883, at Gardner, Mass., and received the degree of bachelor of science from Massachusetts Institute of Technology in 1906, later carrying on graduate study in physics at Columbia University. He was an assistant in the department of physics at MIT, Cambridge, 1906–08, and at Barnard College, New York, N. Y., 1909–11, and instructor in physics at Columbia, 1911–13. In 1913 he entered the research laboratory of Western Electric Company, and in 1919 was placed in charge of toll development. He continued in this capacity at Bell Telephone Laboratories, and recently became director of circuit research. He was awarded honorable mention in the 1933 AIEE national prize award for best paper in theory and research.

A. H. Howell (A'35) has received honorable mention in the 1939 AIEE national prize award for initial paper for his paper "Breakdown Studies in Compressed Gases". Born February 5, 1908, at Sedgwick, Kans., he received the degrees of bachelor of science in electrical engineering, University of Kansas, 1929; and master of science in electrical engineering, Michigan College of Mining and Technology, 1934; and doctor of science, Massachusetts Institute of Technology, 1938. During 1929–30 he was a student engineer in the test course at General Electric Company, Schenectady, N. Y., at the same time studying at Union College. In 1931 he became an instructor in electrical engineering at Michigan College of Mining and Technology, Houghton, and in 1934 left that position on leave of absence to continue graduate study at Massachusetts Institute of Technology, Cambridge. In 1936 he was awarded a Charles A. Coffin Foundation fellowship. Since 1938 he has been a research assistant at MIT.

Irven Travis (A'32, M'40) has received honorable mention in the 1939 AIEE national prize award for best paper in theory and research for his paper "Subharmonics in Circuits Containing Iron-Cored Inductors—II". Born March 30, 1904, at McConnelsville, Ohio, he received the degrees of bachelor of science in electrical engineering, 1926, Drexel Institute of Technology; master of science in electrical engineering, 1928, and doctor of science, 1938, University of Pennsylvania. He was employed on toll-cable engineering by the Bell Telephone Company of Pennsylvania, 1926–28. In 1928 he became an instructor in electrical engineering at the Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, and in 1935 became assistant professor. He has also carried on consulting practice for RCA Victor and General Electric Company. He is also a member of the Society for the Promotion of Engineering Education.

C. R. Davis (A'36) has received honorable mention in the 1939 AIEE national prize award for initial paper for his paper "Signal System, Interlocking Plants, and Automatic Train Control on the San Francisco-Oakland Bay Bridge Railway". Born November 26, 1889, at Valley, Nebr., and educated there, he received his technical training by correspondence. He was in the service of the United States Navy 1907–11, and after two years in the employ of the San Diego (Calif.) Electric Railways, returned to the Navy Department service as ship draftsman, continuing with this work and as warrant carpenter until 1922. He was a mechanical engineer for Link-Belt, Meese and Gottfried Company, San Francisco, Calif., 1922–27, and since 1928 has been in the employ of the State of California, first as junior bridge designing engineer in the department of highways, and since 1931 in charge of electrical work on the San Francisco-Oakland Bay Bridge project.

H. E. Warren (A'02) has received honorable mention in the 1939 AIEE national prize award for best paper in theory and research for his paper "A New Time Standard". Born May 21, 1872, at Boston, Mass., he received the degree of bachelor of science at Massachusetts Institute of Technology in 1894. From 1897 to 1902 he served as engineer for the Saginaw Valley Traction Company, Saginaw, Mich., and from 1902 to 1918 as superintendent and as consulting engineer of the Lombard Governor Company, Boston, Mass. For more than 25 years he has been concerned with the development of electric clocks, first utilizing alternating current for purposes of time-keeping in 1916. He has been president of the Warren Telechron Company, Ashland, Mass., since about 1920. He was awarded the 1934 AIEE Lamme Medal, and in 1935 received the John Price Wetherill Medal of the Franklin Institute. He was recently honored by the National Association of Manufacturers as a "modern pioneer".

E. L. Harder (A'30) has received honorable mention in the AIEE 1939 national prize award for best paper in engineering practice for his paper "Pennsylvania Railroad, New York-Washington-Harrisburg Electrification, Relay Protection of Power Supply System". Born April 28, 1905, at Buffalo, N. Y., he received the degree of electrical engineer from Cornell University in 1926. Immediately after graduation he entered the student course of The Westinghouse Electric and Manufacturing Company at East Pittsburgh, Pa. In 1927 he was transferred to the power engineering department and the next year to the general engineering department. He has continued with the company in various capacities, and is at present central-stations engineer.

A. M. Wright (A'27) assistant engineer, electrical department, the Reading Company, Philadelphia, Pa., has been presented with a 1940 Commemoration Medal by the New Zealand Institution of Engineers for his paper on "Modern Rail Transport". The paper was prepared for presentation at the proposed centennial Engineering Congress, which was cancelled on account of the war in Europe. Mr. Wright is a native (1901) of New Zealand, received the degree of master of science from the University of New Zealand in 1922, and was then employed for two years by Trumbull and Jones, electrical engineers, Wellington. He entered the student course at Westinghouse Electric and Manufacturing Company in 1924, later being transferred to the railway-engineering department. Since 1929 he has been with the Reading Company.

W. B. Bedell (A'35, M'35) formerly an equipment engineer in the long-lines engineering department of the American Telephone and Telegraph Company, New York, N. Y., has been transferred to Chicago, Ill., as district plant engineer in the long-lines division.

E. F. De Turk (A'24, M'30) formerly transmission and distribution superintendent, Metropolitan Edison Company, Reading, Pa., has been employed as electrical engineer by the Long Island Lighting Company, Mineola, N. Y.

W. D. Hull (A'39) formerly head of the electrical department, Steuben County Farm Bureau Co-operative Association, Angola, Ind., is now employed by the Indiana Service Corporation, Fort Wayne.

W. T. Hannum (A'39) has been transferred by the Pacific Gas and Electric Company from the position of assistant engineer in line construction at San Francisco to that of division superintendent of the Coast Valleys division.

Wilbur Roadhouse (A'21) engineer of the plant results section, American Telephone and Telegraph Company, New York, N. Y., has been transferred to the plant employment section, plant operation division.

A. R. Small (M'37) president, Underwriters Laboratories, Chicago, Ill., has been nominated president of the National Fire Protection Association for 1940–41. He is now serving as vice-president of the Association.

A. W. Staller (A'29) factory manager, Crescent Insulated Wire Cable Company, Trenton, N. J., has been nominated a director of the Engineers Club of Trenton for 1940–41.

A. J. Hendry (A'39) formerly engineering aide with the Works Progress Administration, Detroit Lakes, Minn., has been employed as an electrical engineer by the Iowa Public Service Company, Waterloo.

Obituary • • •

George Gibbs (A'05, M'05, F'12) president, Gibbs and Hill, consulting engineers, New York, N. Y., died May 20, 1940. He was born at Chicago, Ill., April 19, 1861, and received the degree of mechanical engineer in 1882 and that of doctor of engineering in 1930 from Stevens Institute of Technology. After two years as chemist for the Orford Copper Company, he went with the Chicago, Milwaukee, and St. Paul Railroad in 1884, as engineer of tests and chemist, and from 1888 to 1897 was mechanical engineer for the road, during which period he developed a system of electric lighting for passenger trains. He was also consulting engineer for the Illinois Steel Company. In 1897 he became consulting engineer for

the Baldwin Locomotive Works and the Westinghouse Electric and Manufacturing Company, and chief engineer of the British and the Continental Westinghouse companies. In 1901 he became first vice-president of the firm of Westinghouse, Church, Kerr, and Company, New York, at the same time being consulting engineer for the Interborough Rapid Transit Company, New York; a member of the board of engineers of the Pennsylvania Terminal; member of the electric traction commission of the New York Central Railroad; and electrical engineer, Long Island Railroad. From 1905 he was chief engineer in charge of the design and construction of Pennsylvania Station and of electric traction for the Pennsylvania Railroad Company. After completion of the station he continued as consulting electrical engineer for the Pennsylvania Railroad and chief engineer of electric traction for the Long Island Railroad. He was a member of the advisory commission of railway experts sent to Russia in 1917 by the United States Government, and was a former member of the New York State Transit Commission. He was the inventor of many railway appliances, notably the first all-steel passenger car, which was adopted by the Interborough Rapid Transit System and later by the Pennsylvania and Long Island Railroads. He was also a member of the American Society of Civil Engineers, which awarded him the Norman Medal, 1911, and the Wellington Prize, 1930, and of The American Society of Mechanical Engineers, American Association for the Advancement of Science, Institution of Civil Engineers of Great Britain, and of several railway organizations, and a past president of the American Institute of Consulting Engineers.

Roger Thomas Smith (M'19) consulting engineer, partner of firm of Highfield and Roger Smith, London, England, died April 28, 1940. He was born in London in 1863, and studied mechanical and electrical engineering at the University of London, receiving the degree of bachelor of science. From 1886 to 1890 he was an apprentice with Hathorn, Davey, and Company, Leeds, makers of pumping machinery, and from 1890 to 1893 was engaged in installing pumping machinery in India as engineer for Easton, Anderson and Goolden, Ltd. He was employed as a resident engineer by the Westminster Electrical Supply Corporation, 1894–95, and as manager for the Imperial Continental Gas Association, supplying hydraulic and electric power to Antwerp, Belgium, 1895–98. From 1898 to 1905 he was a member of the staff of Sir Alex. Kennedy, consulting engineer, and in 1905 he became electrical engineer for the Great Western Railway. He continued in that position about 20 years, then becoming a partner in the consulting firm with which he was associated at the time of his death. He was a past president of the Institution of Electrical Engineers and a member of the Institutions of Civil and Mechanical Engineers, all of Great Britain, and had served as a delegate to the International Electrotechnical Commission.

Arthur D. Stephanus (M'28) assistant to European vice-president, Westinghouse Electric International Company, London, England, died January 3, 1940. He was born in Ohligs, Germany, November 1, 1883, and graduated in law at the University of Kiel and Gottengen. In 1909 he entered the employ of the Westinghouse Electric and Manufacturing Company as a clerk in the accounting department of the East Pittsburgh, Pa., works. In 1911 he was made a correspondent in the industrial and power section and in the export department. He was export representative of the company at the Panama Pacific Exposition, San Francisco, Calif., 1915, and the same year was placed in charge of European negotiations in the export department. In 1919 he went to Norway as a special representative of Westinghouse, becoming head of the power and railway department there. He was placed in charge of London engineering negotiations in 1922, and the following year returned to Norway as London representative for the Scandinavian countries. He had been assistant to the European vice-president since 1931.

Norman Crawford McPherson (A'03) retired consulting engineer, died October 15, 1939, at Short Hills, N. J., according to information just received at Institute headquarters. He was born May 29, 1869, at Gettysburg, Pa., and attended Pennsylvania College and Johns Hopkins University, studying electrical engineering at the latter. He was employed by the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., spending three years as a shop assistant and two years as salesman and engineer before becoming engineer and assistant to the manager of the general manufacturing department. He was later transferred to the engineering staff of Westinghouse, Church, Kerr and Company, New York, N. Y., where he continued for more than ten years, setting up his own consulting practice about 1920. Later he became consulting engineer on railway electrification for S. E. Junkins Company, B. C., Ltd., Vancouver, B. C., Can., and consultant on railway terminals for Edward J. Noonan, Chicago, Ill. He retired about three years ago.

Virginius Daniel Moody (A'99, M'11, F'12) president, Moody Engineering Company, New York, N. Y., died May 30, 1940. He was born February 5, 1878, at Norfolk, Va., and received the degree of mechanical engineer in electrical engineering from Cornell University in 1900. In 1901 he entered the student engineering course at General Electric Company, Schenectady, N. Y., and in 1903 was transferred to the foreign engineering department. In 1905 he was employed as an electrical engineer by F. S. Pearson, consulting engineer, where he had charge of electrical installations in Canada, Mexico, and Brazil. He was employed as assistant engineer on the East River tunnels of the Interborough Rapid Transit Company, New York, N. Y., 1907–08. In 1908 the firm of Hanmer and Moody was formed to engage in general engineering work, and in this capacity Mr. Moody continued to serve as electrical engineer for the Pearson interests in Latin America. The Moody Engineering Company, of which he was president, was formed in 1917.

Frederic Kirk Knowlton (M'25) vice-president and managing director of M. D. Knowlton Company and Auburn Ball Bearing Company, Rochester, N. Y., died in December 1939, according to information just received at Institute headquarters. He was born February 23, 1879, at Chicago, Ill., and received his technical education at Rochester Mechanics Institute, Purdue University, where he studied mechanical engineering, and Columbia University, where he studied electrical engineering. During 1900 he was with the Mexican Petroleum Company, Ebeno, Mex., and the following year became managing director of the Knowlton and Auburn companies, manufacturing paper-package machinery. He served in the ordnance department of the United States Army during the World War, and was a lieutenant-colonel in the Officers Reserve Corps. He was also a member of The American Society of Mechanical Engineers.

Herman Henry Sticht (A'13, M'28) manager and member of the firm of Herman H. Sticht and Company, New York, N. Y., died February 11, 1940. He was born November 5, 1889, at Brooklyn, N. Y., and graduated in electrical engineering at Cooper Union Technical Day School in 1908. During the next two years he was employed by the Electrical Testing Laboratories, New York, N. Y., as technical assistant, and from 1910 to 1912 was assistant in charge of small appliances for the New York office of Siemens and Halske, Berlin firm. In 1912 he became a sales engineer for James G. Biddle, Philadelphia, Pa., having charge of the company's New York office, and continued in this position until the formation of Herman H. Sticht and Company, electrical and industrial instrument engineers, in 1918. The company, of which he was manager, acted as American representatives of several German and Swiss firms.

Edward James Barry (A'10, M'29) consulting electrical engineer, Tacoma, Wash., died March 4, 1940. He was born May 30, 1882, at Glasgow, Scotland, and received the degree of electrical engineer from Glasgow and West of Scotland College in 1906. He was employed in the electricity department of the Greenock Corporation, Greenock, Scotland, and on coming to the United States entered the employ of the Washington Water Power Company, Spokane, in 1909. The following year he was employed by the Potlatch Lumber Company, Potlatch, Idaho, on the electrification of lumber mills, and in 1912–13 was engaged in the electrification of the St. Paul and Tacoma Lumber Company, Tacoma, Wash. In 1913 he started private consulting practice in Tacoma, specializing in industrial power and lighting, principally in the lumber industry, but also for mining and pulp and paper companies and others.

Sheldon Roberts (A'25) electrician, Columbus and Southern Ohio Electric Company, Columbus, Ohio, died April 21, 1940. He was born November 3, 1872, at Columbus, and educated there. From 1903 to 1914 he was employed by the Columbus Railway and Light Company on plant and distribu-

tion work. He was an appraisal engineer for the Ohio State Public Utilities Commission 1915–16, and during the next two years was engaged on construction work on industrial plants, and in 1919 was employed on plant construction and maintenance by the Columbus Railway, Light, and Power Company. He later became electrician, which position he continued to hold after the consolidation of the Columbus and Southern Ohio companies.

Lewis C. Halpin (A'26) assistant superintendent, Niagara, Lockport, and Ontario Power Company, Buffalo, N. Y., died December 11, 1939. He was born September 19, 1898, at Rochester, N. Y., and graduated in electrical engineering from Tri-State College. From 1917 to 1921 he was employed by the Niagara, Lockport, and Ontario company as operator and system operator. In 1923 he became general construction foreman for the New York Power and Light Company, and the next year was made assistant electrical superintendent of the Glens Falls district. He returned to the Niagara, Lockport, and Ontario company in 1928 as superintendent of meters, western division; in 1931 became rural engineer and supervisor of substation construction, Angola division; and later became distribution engineer, and finally assistant superintendent.

Oswald Stickney (A'32) relay test man, Detroit Edison Company, Detroit, Mich., died April 29, 1940. He was born September 13, 1901, at Newburgh, N. Y., and received the degree of bachelor of science in electrical engineering from Detroit Institute of Technology in 1931. He entered the employ of the Detroit Edison Company in 1920 as construction journeyman's helper, being transferred to the electrical maintenance department in 1922 and to the operating department in 1923. He became an operator in the substations department the same year, and in 1926 was transferred to the automatic division and later promoted to foreman operator. He was also a member of the Engineering Society of Detroit.

Edward Robertson Pennell (A'34) chief of design department, Hewittic Electric Company, Ltd., Walton-on-Thames, England, died recently, according to information just received at Institute headquarters. He was born in 1898 at Liverpool, England, and received the diploma in electrical engineering of the Polytechnic, London, in 1922. From 1923 to 1925 he was employed by the British Thomson-Houston Company, Rugby, chiefly on tests. He had been with the Hewittic Electric Company since 1925, first as engineer of the technical department, then as member and finally chief of the design staff. He was also a member of the Institution of Electrical Engineers of Great Britain.

William Wesley Winter (A'38) sales engineer, Allis-Chalmers Manufacturing Company, Chicago, Ill., died December 11, 1939. He was born April 8, 1916, at Chicago, and received the degree of bachelor of science in electrical engineering at Purdue University in 1937. Immediately after graduation he entered the student engineering course of Allis-Chalmers, at West Allis, Wis., and was transferred to the Chicago office as sales engineer in 1939.

Membership • •

Recommended for Transfer

The board of examiners, at its meeting on June 13, 1940, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Colt, N. H., president, South Carolina Electric and Gas Company, Columbia.
David, B. W., wire relations engineer, Cleveland Electric Illuminating Company, Cleveland, Ohio.
Luckiesh, M., director, lighting research laboratory, General Electric Company, Cleveland Ohio.
Trueblood, H. M., protection development director, Bell Telephone Laboratories, New York, N. Y.
Wagner, C. F., consulting transmission engineer, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Weber, H. H., engineer, United States Rubber Company, New York, N. Y.

6 to Grade of Fellow

To Grade of Member

Avtzine, A. D., engineer, Canadian and General Finance Company, Ltd., Toronto, Ont.
Cover, L. G., assistant manager, Cleveland Wire Works, General Electric Company, Euclid, Ohio.
Creese, Myron, professor and head of department of electrical engineering, University of Maryland, College Park.
DeLeau, L. H., assistant engineer, Brooklyn Edison Company, Brooklyn, N. Y.
DeMonte, R. W., member of technical staff, Bell Telephone Laboratories, New York, N. Y.
Farrar, C. L., associate professor of electrical engineering, University of Oklahoma, Norman.
Gates, H. S., section engineer, Westinghouse Electric and Manufacturing Company, Sharon, Pa.
Gutzwiller, W. R., sales engineer, Allis-Chalmers Manufacturing Company, Milwaukee, Wis.
Hague, A. E., electrical engineer, Bell Telephone Laboratories, New York, N. Y.
Harper, J. D., electrical engineer, Aluminum Company of America, Alcoa, Tenn.
Helgason, A., executive vice-president, Chicago Transformer Corporation, Chicago, Ill.
Hoefflin, A. S., personnel director, Louisville Gas and Electric Company, Louisville, Ky.
Kruesi, P. J., president and general manager, Southern Ferro Alloys Company, and American Lava Corporation, Chattanooga, Tenn.
Lindstrom, H. L., electrical engineer, Dravo Corporation, Pittsburgh, Pa.
Mabson, E. B., division engineer, Louisville Power and Light Company, New Orleans, La.
Monteith, A. C., manager, central station engineering, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Montgomery, L. M., Shawnee district engineer, Oklahoma Gas and Electric Company, Shawnee.
Pickens, G. R., assistant operating engineer, Carolina Power and Light Company, Raleigh, N. C.
Plank, W. L., electrical engineer, Pennsylvania Turnpike Commission, Harrisburg, Pa.
Ross, P. M., superintendent of high-voltage laboratories, Ohio Brass Company, Barberton.
Tritle, J. F., engineer, General Electric Company, Erie, Pa.

21 to Grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical Districts. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before July 31, 1940, or September 30, 1940, if the applicant resides outside of the United States or Canada.

United States and Canada

1. NORTH EASTERN

Bivens, M. E., General Electric Company, Schenectady, N. Y.
Harrer, J. M., New York State Public Service Commission, Albany, N. Y.
Martin, A., Southern New England Telephone Company, New Haven, Conn.
Tuthill, H. E., New York State Electric and Gas Corporation, Plattsburg, N. Y.

2. MIDDLE EASTERN

Abbott, W. R., Leeds and Northrup Company, Philadelphia, Pa.
Barbulesco, C. D. (Member), Antioch College, Yellow Springs, Ohio.
Buus, B. R., General Electric Company, Cleveland, Ohio.
Duquette, J. F. (Member), Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.
Hart, J. V., Brown Instrument Company, Philadelphia, Pa.
Laird, J. S., Koppers Coal Company, Pittsburgh, Pa.
Ryder, J. D., Bailey Meter Company, Cleveland, Ohio.
Tarzian, V., 3004 North Howard Street, Philadelphia, Pa.
Weeks, J. R., Westinghouse Electric and Manufacturing Company, Mansfield, Ohio.
Zimmer, A. A., Rowan Controller Company, Baltimore, Md.

3. NEW YORK CITY

Doughty, G. F. (Member), Simplex Wire and Cable Company, New York, N. Y.
Falck, E., Consolidated Edison Company of New York, Inc., New York, N. Y.
Jatlow, J. L. (Member), Photo Positive Corporation, Shoreham, Long Island, N. Y.
Johnson, R. M., A Company, 51st Signal Battalion, Fort Monmouth, Oceanport, N. J.
Haaland, I., Brooklyn-Queens Transit Company, Brooklyn, N. Y.
Moore, F. A., Public Service Electric and Gas Company, Passaic, N. J.
Rentschler, H. C. (Member), Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.
Scher, V. A., care of Richards and Geier, New York, N. Y.

4. SOUTHERN

Beal, J. A., Memphis Light Gas and Water Division, Memphis, Tenn.
Booth, C. V., Florida Power and Light Company, Miami Beach.
Love, G. A., Robert and Company, Atlanta, Ga.
Schindler, L. J., Jr., 622 Drew Street, Lake Charles, La.

5. GREAT LAKES

Brede, E. F., 18900 Warrington Drive, Detroit, Mich.
Fox, H. N. (Member), Commonwealth and Southern Corporation, Jackson, Mich.
Gilborne, S. S., Jr., Aermotor Company, Chicago, Ill.
Unger, A. M., Pullman Standard Car Manufacturing Company, Chicago, Ill.
Miller, E. F., Peoples Power Company, Moline, Ill.
Schafer, V. E., Jr., General Motors Corporation, Detroit, Mich.

7. SOUTH WEST

Bayless, W. T., Black and Veatch, Kansas City, Mo.
Richardson, A. I. (Member), Allis Chalmers Manufacturing Company, Dallas, Tex.
Smith, P. deW., Pennsylvania Shipyards, Inc., Beaumont, Tex.
Stahl, C. R. (Member), Panhandle Power and Light Company, Borger, Tex.
Wilson, C. W., Electric Storage Battery Company, Dallas, Tex.

8. PACIFIC

Bush, J. B., Parker Electric Light Plant, Parker, Ariz.
Campini, E. J., Market Street Railway Company, San Francisco, Calif.
Carlson, R. L., Southern California Edison Company, Ltd., Alhambra, Calif.
Haack, V. L., Pacific Gas and Electric Company, San Francisco, Calif.
Moody, A. W., General Electric Company, San Francisco, Calif.

9. NORTH WEST

MacPherson, R. M., Wagner Electric Corporation, Portland, Ore.
Mushlitz, A. R. (Member), Clearwater Valley Light and Power Association, Inc., Lewiston, Idaho.
Perry, R. T. (Member), Boaneville Project, Portland, Ore.
Pound, J. C., Corps of Engineers, United States Army, Bonneville, Ore.
Talbott, A. L., Washington Water Power Company, Spokane.

Total, United States and Canada, 47

Elsewhere

De, A. C., 6/1 Kankila Road, Ballygunge, Calcutta, India.
Feinberg, R. (Fellow), University of Manchester, Manchester, England.
Pinheiro, H., Pindamonhangaba, Estado S. Paulo, Brazil.

Total, elsewhere, 3

Transactions

Preprint of Papers and Discussions Comprising Pages 369–416 of the 1940 Volume

The Application of Traction Motors

F. E. WYNNE
FELLOW AIEE

G. M. WOODS
NONMEMBER AIEE

Synopsis: The application of traction motors is based fundamentally on speed-time curve calculations. This method has been used for many years and is familiar to electrical engineers engaged primarily in transportation activities. Many other engineers infrequently encounter problems of traction-motor application but are not conversant with the effect which variations in service conditions produce on vehicle performance. This paper points out certain recent changes in transportation requirements tending toward greater standardization of equipment, and summarizes the effects of varying operating conditions. The broad basis of economical application is indicated.

THE application of all types of traction motors is based fundamentally on the speed-time curve. Speed-time curve calculations may be unnecessary for many specific applications, but a knowledge of the principles is essential to correct application of motors. The methods of calculation are covered fully in textbooks and for many years have been included in college courses in railway engineering. The purpose of this paper is to illustrate the application of the principles and show the effect on traction-motor performance of varying the more important determining factors.

In the past few years the business of electric transportation has undergone important changes. These have produced changes in apparatus requiring a different technique in application. Until the year 1928 surface cars, rapid-transit cars, and light traction locomotives were propelled by axle-mounted motors driving through single-reduction gears. At that time the lines of traction motors ranged from 25 to 250 horsepower, and the work of application consisted largely of the motor and gear ratio selection to meet the particular service requirements. For this it was usually necessary to calculate the service performance of the motor, chosen on the basis of the engineer's judgment. Motors were self-ventilated and while attention had to be paid to commutating requirements under the most severe conditions of operation and to short-time overloads, the ability to operate within the motor's continuous rating generally insured satisfactory all-around performance. The steady decrease in the cost of energy and increase in car operators' wages had reduced energy consumption to a secondary position instead of one of prime importance which it had occupied 25 years before.

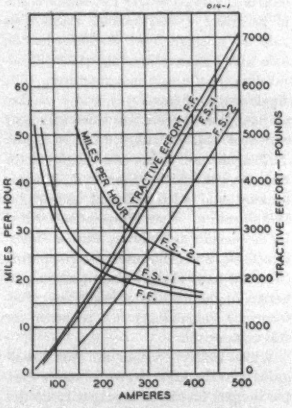


Figure 1. Trolley-coach motor A

Gear ratio, 10.61:1; wheel diameter, 40 inches; volts, 550

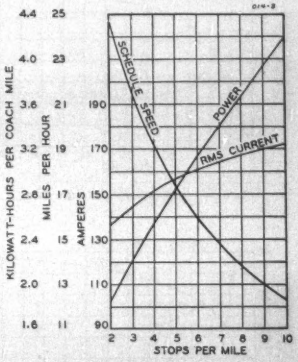


Figure 3. Trolley-coach operating characteristic

Motor *A*, F.S.-1 field strength, normal acceleration and braking

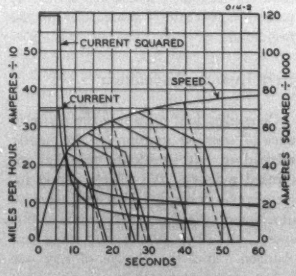


Figure 2. Trolley-coach performance curves

Motor *A*, F.S.-1 field strength, normal acceleration and braking

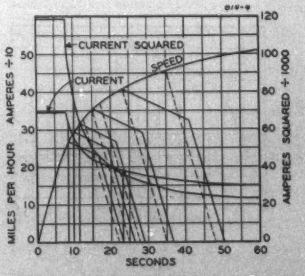


Figure 4. Trolley-coach performance curves

Motor *A*, F.S.-2 field strength, normal acceleration and braking

Paper 40-14, recommended by the AIEE committee on transportation, and presented at the AIEE winter convention, New York, N. Y., January 22–26, 1940. Manuscript submitted October 23, 1939; made available for preprinting December 11, 1939; released for final publication February 23, 1940.

F. E. WYNNE is section engineer, railway application, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.; G. M. WOODS is with the same company.

Street Cars

Today street-car and trolley-coach motors are of the light-weight high-speed highly ventilated type. Short-time overloads and accelerating currents must be given more detailed examination. Also standardization of vehicles and equipments has progressed. Practically all city street cars purchased are of the Presidents' Conference Committee or similar type utilizing the same electrical equipment. This was the outgrowth of several years' study. All cars are of nearly the same weight and use the same gear ratio and wheel diameter. A study of operating conditions throughout the country was made and the electrical equipment was then designed to meet the maximum safe speed, balancing speed, and acceleration and electric braking rates specified by the committee and to have adequate capacity for the most severe service likely to be encountered. With such standardization, applications to specific cities obviously involve little additional work.

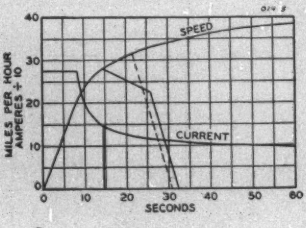


Figure 5. Reduced acceleration rate

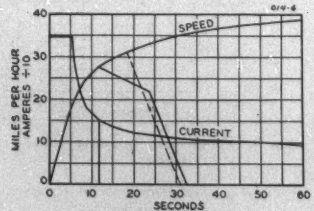


Figure 6. Reduced braking rate

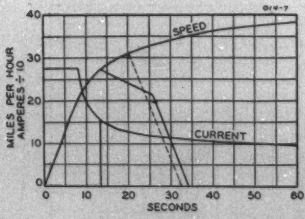


Figure 7. Reduced acceleration and braking rates

Figures 5–7. Trolley-coach performance curves

Motor *A*, F.S.-1 field strength

Trolley Coaches

Trolley coaches came into prominence in 1928. Two sizes are in common use: 30- to 33-passenger and 38- to 44-passenger capacity. The 30-passenger coach is propelled by one 65-horsepower series motor and the 40-passenger coach by two such motors, one 125-horsepower series motor, or one 140-horsepower compound motor. The rear axle of the 30-passenger coach generally has worm drive with 10.25:1 gear reduction. The rear axle of the 40-passenger two-motor coach is generally a double-bowl worm-drive axle or a single-bowl double-reduction axle with a gear ratio of about 9.25:1, depending on the axle manufacturer. The single-motor 40-passenger trolley coaches all have double-reduction axles with gear ratios of approximately 9.25, 10.5, and 11.5 available. Also, the single motor may be used with or without dynamic braking and with different degrees of field shunting. The equipment best suited for a specific application can be determined by economic analysis, comparing the total fixed charges and operating expenses of the various alternatives. Performance calculations are required for this comparison.

While trolley coaches are not standardized to the same degree as street cars, the weights for the same capacity do not differ widely. Hence, when a motor is designed for trolley-coach service, definite effort is made to cover the probable field of application and generally only one capacity of motor is available. Evidently much progress toward standardization has been made.

Performance Calculation

Generalizations regarding the performance of traction motors are frequently misleading. It is safe to say that increased weight of the vehicle always increases energy consumption and increased duration of stop always decreases schedule speed, all other factors remaining unchanged. But the change of any one factor may automatically change some other factor. For instance, if the weight is changed, with a given set of conditions, either the speed margin or the schedule

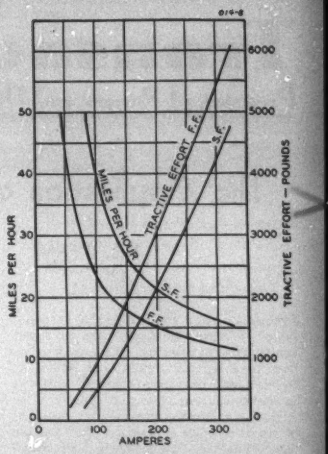


Figure 8. Trolley-coach motor B

Gear ratio, 10.61:1; wheel diameter, 40 inches; volts, 550

speed must be changed. Both cannot remain the same. Also it is incorrect to assume that changes of the character discussed will always result in the same percentage change, because while the same trend exists the amount of the change is dependent on the characteristics of the particular motor and other conditions.

Because the trolley coach retains some latitude in the selection of electrical equipment and gear ratio, it is selected to illustrate the method of application. The following basic conditions apply.

The coach weight with average passenger load is 23,000 pounds. The motor has a one-hour rating of 125 horsepower. The gear ratio is 10.61:1 (as extensively used). The effective rolling diameter of the tires is 40 inches. The average voltage is 550, which is typical. Train resistance increases as the speed of the vehicle increases but it varies so widely

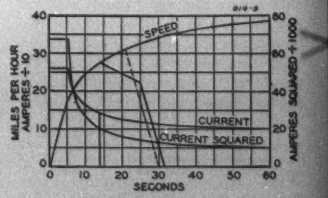


Figure 9. Trolley-coach performance curves

Motor *B*; average voltage, 550; gear ratio, 10.61:1; normal acceleration and braking

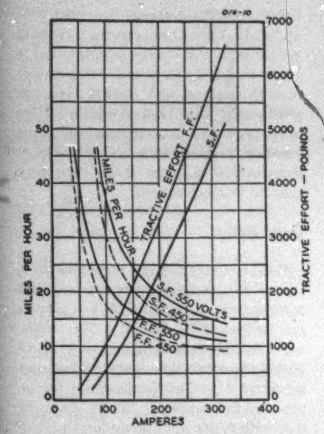


Figure 10. Trolley-coach motor B

Gear ratio, 11.42:1; wheel diameter, 40 inches; volts, 550

with type and condition of pavement that a constant value of 40 pounds per ton is used during motoring. This is amply high for the speeds normally reached. During coasting, the vehicle supplies the no-load losses of the axle and motor. The coasting resistance is thereby increased and a constant value of 47 pounds per ton is used. An average accelerating and braking rate of 3.5 miles per hour per second is used and is as high as can be employed consistently. The minimum time in which the equipment can travel a certain distance under these conditions is increased by a "speed margin" of five per cent (to allow for unavoidable interferences) and schedule speed, motor heating (root-mean-square current) and energy consumption are calculated on that basis.

Figure 1 shows the performance curve of motor *A* on full field and with two percentages of field shunting. The relatively small amount of shunting is designated F.S.-1 and the large amount F.S.-2. By using the motor characteristic, figure 1, and the accepted methods of calculation, the speed-time, current-time, and current squared-time curves are derived and plotted. Starting tractive effort is 4,490 pounds. Accelerating current is 346 amperes. The full-field motor curve is reached at 17.2 miles per hour and the S.F.-1 curve at 18.4 miles per hour. Five different runs between 0.076 mile and 0.369 mile are shown in figure 2.

The one-sixth-mile run may be taken as typical of average trolley-coach service. The required distance without coast is obtained in 29.1 seconds. Adding five per cent speed margin for the typical run with coast gives a running time of 30.56 seconds. The average duration of stop is taken as 7 seconds. Therefore, the total time for this run is 37.56 seconds and the schedule speed is 16.0 miles per hour. The heating current for the total time is 161 amperes which is within the capacity of the motor. The energy consumption is found to be 3.15 kilowatt-hours per coach mile at 550 volts.

The calculated coach performance for the range of runs indicated is shown in figure 3, plotted with stops per mile as abscissas. The decrease in schedule speed and the increases in energy consumption and heating current as the frequency of stops increases are evident. For example, an increase in stops per mile from six to ten decreases schedule speed 23 per cent, increases energy consumption 33 per cent, and heating current 7 per cent.

Field Shunting

The characteristic curve of motor *A*, figure 1, shows by curves F.S.-2 the performance of the motor with fields shunted much more than for F.S.-1. Equipments embodying this characteristic are operating in two cities where they have proved to be very popular with both operators and the public. Their principal advantage lies in maintaining a high rate of acceleration up to high coach speeds and thus enabling the trolley coach to hold a position of superiority where traffic moves unusually rapidly. On the other hand, equipments having the characteristics shown by F.S.-1 are in service in many cities and their performance on the street is entirely successful.

Figure 4 shows the calculated performance with F.S.-2. The full-field accelerating current is the same as for figure 2 but the shunted-field curve is reached at a speed of 25.6 miles per hour instead of 18.4 miles per hour as with F.S.-1. A speed of 30 miles per hour is reached in 10.2 seconds instead of 15.77 seconds. The resulting performance compares with that for F.S.-1 as follows:

Stops Per Mile		Schedule Speed (Miles Per Hour)	Energy Consumption (Kilowatt-Hours Per Coach Mile)	RMS Amperes
2	F.S.-1	24.6	1.84	136
	F.S.-2	28.8	2.21	175
6	F.S.-1	16.0	3.15	161
	F.S.-2	16.7	3.47	186
10	F.S.-1	12.3	4.19	172
	F.S.-2	12.5	4.25	181

Attention is called to the fact that the increased speed of the motor affects schedule speed, energy consumption, and root-mean-square amperes most in the infrequent-stop service and least in the frequent-stop service. The reason for this is the greater amount of operation on the shunted field curve as length of run increases.

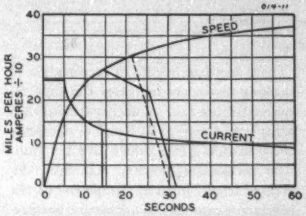


Figure 11. Average voltage, 550; normal acceleration and braking

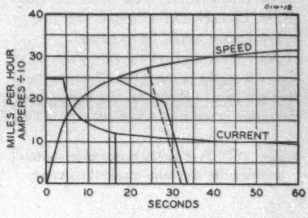


Figure 12. Average voltage, 450; normal acceleration and braking

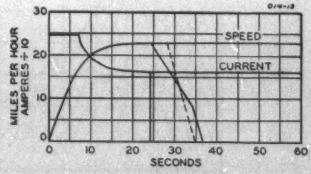


Figure 13. Average voltage, 550; normal acceleration and braking; up five per cent grade

Figures 11–13. Trolley-coach performance curves

Motor *B*; gear ratio, 11.42:1

Acceleration and Braking

Changes in rates of acceleration and braking affect performance. Taking exactly the same conditions as for figure 2, except rate of acceleration and braking, the performance on a one-sixth-mile

run has been calculated for the following combinations:

	Rate of Acceleration (Miles Per Hour Per Second)	Rate of Braking (Miles Per Hour Per Second)
Figure 5	2.5	3.5
Figure 6	3.5	2.5
Figure 7	2.5	2.5

Any decrease in rate of acceleration or braking obviously increases the time required for the run. A decrease in accelerating rate alone, as in figure 5, decreases the schedule speed almost five per cent. The accelerating current has been decreased from 346 to 274 amperes but the energy consumption is unchanged because the duration of constant current has been increased. If, instead of maintaining the same speed margin, an attempt were made to make the same schedule speed as in the original example the energy consumption would be increased.

A decrease in braking rate only, as in figure 6, again reduces the schedule speed five per cent. However, the energy consumption is reduced seven per cent. This results from retaining the economically high rate of acceleration and the covering of a greater portion of the distance during coasting and braking when power is not applied to the motors.

When both accelerating and braking rates are reduced as in figure 7, the schedule speed is reduced almost nine per cent and energy consumption is reduced only five per cent.

Slow-Speed Motors

The foregoing comparisons have been with one specific motor. The effect of using a motor with different characteristics, motor *B* of figure 8, will be considered now. This motor has a much slower full-field speed curve than motor *A* and a steep-shunted field curve. In the balancing-speed range the speeds are the same. The effect of the slower full-field curve is to increase the tractive effort per ampere. As a result the starting current is only 260 amperes, or 25 per cent less than the 346 amperes starting current of motor *A*. Figure 9 shows the curves for a one-sixth-mile run.

The schedule speed is 15.64 miles per hour; only 2.3 per cent less than with motor *A*. But heating current is reduced 20 per cent and energy consumption is 17 per cent less. In several cities, motors of both types *A* and *B* have been applied on the same type of vehicle. They have been able to maintain the same schedule speeds and the saving in energy consumption of motor *B* has been very close to that calculated.

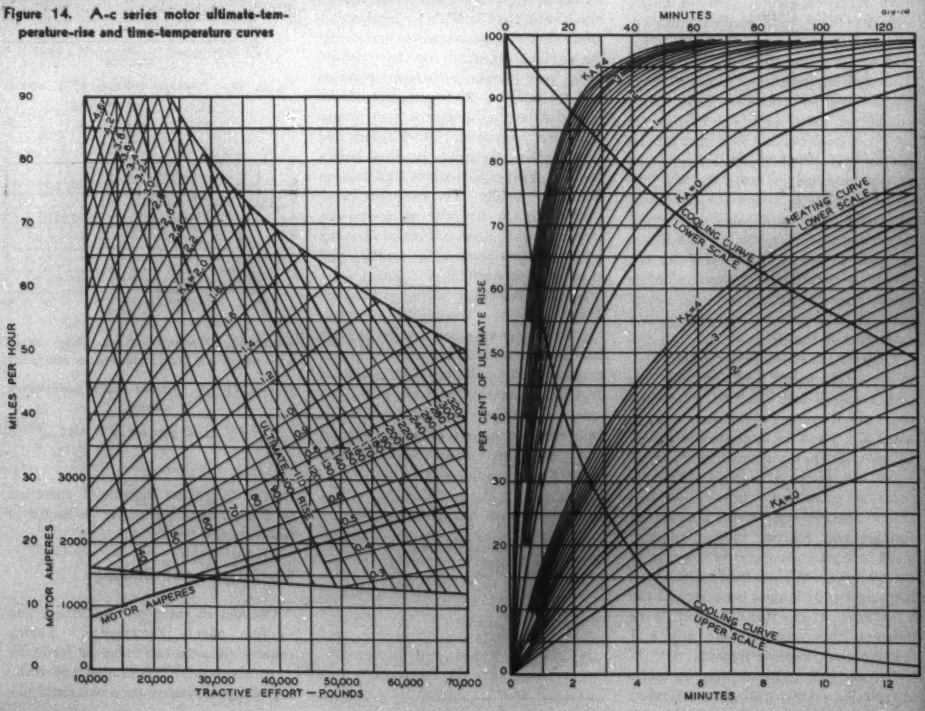
Gear Ratio

With less severe speed requirements it is possible to secure even more economical performance with motor *B* by using a gear reduction of 11.42:1. The motor curve for this gearing is shown by figure 10 and the curves for a one-sixth-mile run by figure 11. The accelerating current becomes 247 amperes, 29 per cent less than with motor *A*. Energy consumption is 20 per cent less but schedule speed is reduced only 3 per cent.

Voltage

Figure 12 shows the effect if the average voltage at the motor is reduced from

Figure 14. A-c series motor ultimate-temperature-rise and time-temperature curves



550 to 450 volts, all other conditions being the same as in figure 11. The schedule speed is reduced almost 5 per cent and energy consumption at the coach is reduced 15 per cent. However, low voltage is usually the result of drop in the distribution system, hence it is necessary to compute the energy delivered by the substation to obtain a true comparison. At 600 volts the values become 2.75 and 2.86 kilowatt-hours per coach mile for the conditions of figures 11 and 12 respectively. The reduction in energy at the car due to slower schedule is more than offset by the energy lost in distribution. Also in any particular service a definite schedule speed must be maintained. Low voltage reduces the amount of coasting and increases the energy consumption at the substation even more than calculated above on the basis of a fixed speed margin.

Grades

Few cities are entirely level. Obviously grades increase running time and energy consumption. When the profile of a line is rolling with its two ends at approximately the same elevation, it is customary to calculate performance on the basis of an equivalent grade resistance. The percentage of equivalent grade is calculated by adding all the rises in feet in a round trip, multiplying by 100, and dividing by twice the round-trip distance in feet.

Where there is a long grade in one direction and a material difference in elevation of the ends of the line it is necessary to calculate both an up-grade run and a down-grade run. Where there are short down grades at various points in a long continuous up grade it is customary to calculate the average percentage grade by adding the rises in feet, subtracting half the sum of the drops, multiplying by 100, and dividing by the length in feet. This formula, as well as that for equivalent grade, is based on the assumption that half of the potential energy in the vehicle at the top of any rise is recovered in useful work in descending the grade and that half is dissipated in the brakes.

On the usual hilly route the profile must be analyzed and divided into various equivalent-grade, up-grade, and down-grade sections. Separate calculations of performance are made for each section and the results combined on the basis of the lengths of the sections. In steam-railroad electrification and rapid-transit work, where the stopping points are definitely known continuous speed-time curves are frequently calculated and the effect of each condition of grade, curve, and speed restriction is taken into account. This process is rather laborious and is used only when the service cannot be represented properly by typical runs.

Figure 13 shows the performance of the same equipment as figure 11 under the same conditions except on a five per cent up grade and with accelerating current held at the same value as on the level. The accelerating rate, therefore, is reduced by the grade resistance of 100 pounds per ton to 2.5 miles per hour per second. Schedule speed is 12 per cent less but energy consumption is increased 75 per cent from 2.52 to 4.40 kilowatt-hours per coach mile.

Rapid Transit

In general, rapid-transit motor application follows the practice used for surface vehicles. In rapid transit, high-speed spring-supported motors with separate gear units have not yet been accepted generally, largely because rapid-transit equipment has always been applied on a very conservative basis. The reasons for this conservatism are (*a*) the seriousness of any failure which may cause a road delay in subways or on elevated structures, (*b*) the large number of cars usually involved in any extension of service, and (*c*) the requirement that new equipment must operate in train with existing equipment. However, in spite of these conditions there is a definite trend toward the use of lighter-weight higher-speed equipment.

Locomotives

The application of motors on locomotives differs from the application on cars or trolley coaches in some respects. The latter vehicles are seldom, if ever, subjected to runs of long duration with the motor tractive effort close to the slipping point of the wheels. Locomotives frequently start and pull trains for long distances under such conditions. Therefore, the locomotive motor must be able to commutate successfully the current required with good, sanded rail. Effort is made to apply electric-locomotive equipment so that the motors in the specified service will not be damaged by any conditions within the limits of adhesion between wheel and rail.

Heavy traction locomotives may run without stops for distances of 50 miles or more over a varied profile. The application of a-c series motors, used principally on such locomotives on electrified railroads, presents problems different from

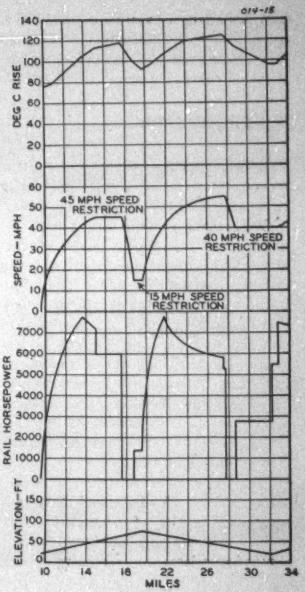


Figure 15. A-c locomotive. Profile, horsepower, speed, and temperature curves

those encountered on d-c motors. The factors which produce heating of the motors are different. The heating of a d-c motor depends almost entirely on the current and ventilation. In addition, the heating on an a-c motor is greatly affected by speed; that is, the current rating increases with reduction in speed. As a result, motor heating depends on horsepower output rather than on current. Consequently, some method other than the calculation of root-mean-square current must be used to determine the heating of a-c series motors.

A series of heating and cooling curves for the a-c motor over its entire operating range is determined by test. For each section of the profile the tractive effort and speed are calculated and, from the curves at the left of figure 14, the corresponding values of K_A and ultimate temperature rise are read. The number of minutes for the section is calculated from speed and distance. For this number of minutes the per cent of ultimate rise for the value of K_A is read from the curves at the right of figure 14. This percentage converted into degrees gives the temperature rise in the section. The cooling curve shows the per cent of initial temperature at the end of various durations of no-load operation. When

the calculations for a run are completed a continuous temperature-rise curve over that run is available. A typical section of such a curve is shown in figure 15.

Self-Propelled Vehicles

On self-propelled vehicles the electric generator and motor serve simply as a means of smoothly transmitting power from the engine, running at relatively constant speed, to the vehicle's driving wheels which run at speeds between zero and the maximum required. The problem is so to design the electric machines that minimum power is lost in transmission and that the engine is fully loaded over a wide range of operating conditions. In the case of locomotives or cars operating on long runs the electrical equipment in general must be capable of utilizing full engine power for long periods. In the case of busses in frequent stop service, full engine power is exerted only a small percentage of the time and electrical equipment capable of transmitting full engine power continuously would be uneconomically large and expensive.

Gear ratio has little effect on the schedule speed of a self-propelled bus with electric transmission in city service because the input to the electrical equipment is fixed. Therefore, with a specific engine output the tractive effort at any given vehicle speed within the normal operating range is the same regardless of gear ratio, except for the difference in efficiency resulting from different values of current and voltage. The greater the gear reduction with a specific equipment, the greater is the tractive effort at starting, but the lower is the vehicle speed at which the engine is not fully loaded by the generator and "runs against" the governor. Greater gear reductions result in lower current demand and hence lower temperature rise of electrical equipment.

Summary

The basic methods of calculating the service performance of traction motors have proved to be correct throughout years of application. In some installations, at first glance, results in service seem to contradict theoretical calculations. Careful analysis of such cases discloses that the service conditions or methods of operation differ from the basis of calculations. It has been seen that the calculations themselves are simple. To determine the correct basis requires experience and judgment.

To secure maximum economy of operation, the total operating costs must be studied for each application. Higher schedule speeds tend to reduce expense of vehicle operators but increase power costs. For each particular service it must be determined whether increased schedule speed will actually reduce the number of vehicles in service or merely increase wasted time at the ends of the route. On the other hand, it must be borne in mind that high schedule speeds have merchandising value and usually attract additional patronage.

The greatest power economy in city service is obtained by providing motors with the slowest practicable full-field speed and with a shunted-field speed which can meet the requirements of schedules with a speed margin of some five to ten per cent. The highest accelerating and braking rates practicable should be maintained. Vehicles and equipment of the lightest weight consistent with reliable operation and low maintenance should be employed.

In the future a greater degree of standardization may be expected. The continued use of electrical apparatus in transportation is dependent on obtaining the maximum economy both in first cost and operating cost. According to most recent data 8,000,000,000 kilowatt-hours are consumed annually by the electric railways. All electrical engineers should be interested in retaining and increasing this load for the electrical industry.

A New Postgraduate Course in Industry in High-Frequency Engineering

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THOSE FIELDS of engineering which utilize high-frequency electric currents and electronic devices have long ago graduated from the trial and error stage. The empirical experimenter who is ingenious and observant will always be useful, especially in some new and fruitful phase of the art not yet well understood. However, reliance has for many years been placed upon the ability of the engineer to design analytically upon a sound basis in the underlying theory and analytical tools are recognized as valuable aids and guides in laboratory work.

The newer fields of application in radio have made the engineer's need for a firm foundation in theory constantly more essential. Thus, the complication in both number and operation of the components of a television system is such that the ability to predesign results in untold savings. The problems of short waves have made clear to the engineer that many concepts in electricity he had regarded as basic are narrow in scope, limited to comparatively low frequencies, and inadequate if not altogether erroneous when applied to ultrahigh frequencies.

A major recent development in radio is a system combining frequency modulation with limiters. This outstanding improvement was due to a man who possessed intuition, vision, and courage. He is also a fine analyst in the broad sense of understanding exceptionally clearly what goes on in radio circuits. Success would not have been attained without the intuitive invention but it is doubtful if intuition alone could have solved the problem if the inventor had not had a very clear idea of the theory involved. Of course, after the whole problem had been solved technically, great vision and courage and determination were necessary to bring it to its present state of acceptance.

Even those workers who possess the highly inventive type of mind and are able to find new ideas with only a hazy notion of the theory behind their experiments can have their programs radically accelerated by the assistance of fellow workers who can correlate experiment with sound theory.

To push forward the understanding of high-frequency theory, and provide a solid foundation for good design and

Paper 40-75, recommended by the AIEE committee on education and the subcommittee on electronics, and presented at the AIEE winter convention, New York, N. Y., January 22-26, 1940. Manuscript submitted November 22, 1939; made available for preprinting January 5, 1940; released for final publication February 29, 1940.

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development requires that the engineer possess: (1) the analytical tools; (2) the ability to apply these tools to the solution of practical engineering problems. The latter characteristic includes more than simply the ability to substitute into a formula; it involves also the ability to extract out of a practical situation the problems whose solutions have bearing on the ultimate answers, the judgment to introduce the usually necessary approximations, and finally the important ability to express the results in an easily understandable and useful form.

Need for Course in Industry

Men rarely come to industry direct from college with the amount of training in the difficult radio field that is required for the possession of both of the foregoing characteristics. This is not stated in the nature of a criticism of college curricula. At least as far as undergraduate work is concerned, it is undoubtedly best to give basic and general training to engineers, leaving the study of more specialized branches of engineering to postgraduate work as is being done in many colleges.

Among the subjects of special interest to high-frequency workers but for which there is little time in an ordinary four-year course (and in many five-year courses), is the study of Maxwell's field equations. Unless time is devoted to a study of this theory in postgraduate work, even a phenomenon so fundamental to radio engineering as the radiation of energy by electromagnetic waves is seldom understood. Displacement current may be somewhat familiar to the student but the consequences of the concept are usually not appreciated until problems concerning it are met and solved. Without a feeling for retardation in electrical phenomena one is usually limited to concepts of inductance and capacitance which are valid only at low frequency. Even aside from retardation effects, it is necessary that the high-frequency engineer possess a broader notion of resistance, inductance, and capacity in which current distribution and proximity effects play a part, so that these circuit concepts are not thought of as necessarily independent of frequency. The ideas under discussion here are not new, but there is a need for more young men who thoroughly understand them.

Because it is necessary to teach circuits in a way that will be useful to students who may ultimately enter either the power or communication fields, circuit equations and concepts are most often introduced to the student as one branch of science he must master, and field theory (if treated at all) as another. When the frequency of the circuit is increased to the point that radiation of energy must be considered, the student without additional training is apt to find his circuit concepts inadequate in explaining the phenomenon. For ordinary circuits, he thinks of Kirchoff's and Ohm's laws; for radiation problems there has been little opportunity to equip him with more than a formula or two whose derivation he may not have seen, still less understood.

Transmission-line theory is usually presented entirely from the "voltage along the line" and "current along the line" standpoint. The notion of the transmission of electrical energy by means of propagating fields is so often passed over, or only mentioned as "an interesting way of looking at transmission," that when confronted with the problem of analyzing the transmission of power down the inside of a single hollow conducting tube "wave guide", the student has no basis for attack. Even if time has been found to treat the field concept in college and the graduate does possess a certain amount of appreciation for it, to set up the electromagnetic field equations and solve them in practical cases requires ordinarily more mathematical ability than the student has had a chance to acquire.

In acquainting the student with the operation of electron tubes, the "machinery" of the electronics or radio engineer, the available college time must be limited to the simpler problems. Thus this theory is usually taught in such a way that when higher frequencies are used and problems arise because of the presence of previously negligible transit-time effects, the student must discard what he thought were the basic concepts underlying amplifier or oscillator action and learn a set of more fundamental ones. For example, he can no longer assume that the number of electrons arriving per second at the anode of a diode is exactly equal at every instant to the number leaving the cathode; nor must he take as fundamental that a negatively biased electrode which collects no electrons does by that token not require any driving power.

Some students with more years of college study or an unusual selection of courses obtain a thorough background in the fundamentals of electricity and magnetism and the mathematical tools necessary to apply the theory. To these cases the examples cited are not applicable. However, it is again rare indeed that these men will have had the exposure to the practical type of problem in which the problems themselves are often difficult to isolate and the theory can be used only after a number of engineering approximations have been made.

In general, it may be said that there are three kinds of ability required in engineering work. Analytical ability, though essential, is not the only one demanded by industry. The highly inventive type of mind that contributes valuable ideas, often without apparent need for theoretical background, is one that is unfortunately too rare. The third type of ability, to follow directions and copy designs, also has its place. It is upon the first two kinds of ability, however, that we must depend for technical advancement.

Now, the ingenious inventor is difficult to recruit, for the colleges (especially in undergraduate years) have little time to detect this ability. The analytical man on the other hand is selected by his college record and examinations and trained with success. Since postgraduate study is essential to supply men for the more difficult phases of high frequency and electronics, and since the combination of analytical and experimental ability is so desirable in this field, it has seemed logical to equip men with analytical tools while actually engaged in practical work in industry. This work allows the man with inventive ability to strengthen it while engaged in experiment or design; against it as a background, the newly learned theory may become at once an active tool.

As John Dewey, the famous philosopher and educator has said:*

"But there is all the difference in the world whether the acquisition of information is treated as an end in itself, or is made an integral portion of the training of thought. The assumption that information which has been accumulated apart from use in the recognition and solution of a problem may later on be freely employed at will by thought is quite false. The skill at the ready command of intelligence is the skill acquired with the aid of intelligence; the only information which, otherwise than by accident, can be put to logical use is that acquired in the course of thinking. Because their knowledge has been achieved in connection with the needs of specific situations, men of little book-learning are often able to put to effective use every ounce of knowledge they possess; while men of vast erudition are often swamped by the mere bulk of their learning, because memory, rather than thinking, has been operative in obtaining it."

This theory of education agrees with the experience of the General Electric Company.

* From his book "How We Think," pages 52 and 53.

Postcollege Training at the General Electric Company

The General Electric Company has had experience in fitting men with the essential qualifications implied above for work in electrical, mechanical, and thermal engineering. The three-year postgraduate course, known as the Advanced Course in Engineering,† has been in operation for about 16 years during which time it has graduated several hundred engineers. In view of the successful operation of the courses in other branches of engineering a new section of the advanced course has been organized to cover electronics and high frequency engineering. Before describing the new course it will be well to summarize briefly the aims and operation of the advanced course in general.

When the advanced course was instituted, the company realized that its achievement thus far had rested in a large measure upon the sound technical foundation laid by the pioneers and that future progress would depend on filling their places with high-caliber men who had the ability to think along fundamental lines, apply their knowledge to the development of improved apparatus, and deal generally with the advanced theoretical aspects of engineering work. It was recognized that such work is essentially mathematical in character and that in order to deal effectively with such problems one must be able to use mathematics as a tool in the application of fundamental laws of physics to the problems of engineering and must have a real appreciation of its significance as an aid in straight thinking.

Engineering graduates from American colleges, however, usually did not have sufficient training along the necessary lines. Most of them had no mathematical training beyond the calculus, and those who had studied differential equations had not learned how to make use of them in the analysis of physical problems. There were coming to the company relatively few engineers who were thoroughly grounded in methods of analysis. The courses in many colleges had become too practical; men were being taught routine rule-of-thumb methods of design, and there was insufficient emphasis on thinking problems through by the use of fundamental principles.

The experience of the founders of the course, R. E. Doherty and A. R. Stevenson, Jr., and of those with whom they were associated indicated very definitely that in order to be effective the course should have two major objects. These objects were to train men:

1. To apply the fundamental principles of engineering to the solution of their problems.

2. To present the results of their work clearly and concisely, whether in written form or orally, so that others might easily understand and use these results.

In the 16 years since its founding these objectives of the course have been adhered to.

The first year, or *A* class, is common to all sections of the course and is made up of 30 to 40 men of the testing department who have been with the company only a short time. Entrance is competitive and selection is made from among the applicants on the basis of an examination, school records, and personal interview. Personality and ability to co-operate with others are carefully considered, as well as technical ability.

Those selected remain in the testing department and obtain the same experience there as those not taking the course. In addition, they spend a half day a week in class on company time.

The work during the first year consists of a study of the application of the fundamentals of engineering to the solution of problems involving mechanics, thermodynamics, heat transfer, electricity, and magnetism. Throughout the three years of the course, as far as possible the problems selected are ones which have actually arisen in the engineering departments of the company. In many cases unsolved problems have been assigned, and the classes have thus been given the chance to be of assistance in useful engineering work. These problems differ from most textbook problems in that the students are expected to select from a group of facts those which are necessary for the solution. Another important aspect is that usually it is necessary for the students to make a number of simplifying assumptions in order to bring the problem within the range of practical mathematics. About 15 to 20 hours a week are spent at home by the students in solving and writing up their problems.

Lecture Material in the High-Frequency Section

A few of the 12 or 15 men selected each year from the *A* class for the upper classes are given the final two years of that part of the course dealing with electronics and high frequency. They leave the testing department and are taken directly on the payroll of the advanced course. While on this payroll the men continue to spend at least a half day a week in class on company time. The class work during the second and third year is illustrated by the accompanying chart giving briefly the work of the first year, and in more detail, the lectures of the second and third years.

This chart is intended to show how the mathematical, physical, and design material is developed simultaneously so that uppermost in the student's mind is the regard for the analytical processes as useful tools when properly applied in the solution of engineering problems. The subjects given in the table are intended to be merely illustrative and will change from year to year, although the fundamental nature of the lecture material is preserved. The material is adjusted to fit the needs of the company, the problems which arise, and the previous background of the students such as the *A* class. The technical lectures are given by a great many men from many different departments. In this way, the subjects are presented from many different points of view and there is little danger of the course becoming "inbred".

Problem Assignments in High-Frequency Section

The greatest part of the value of the course is obtained by the student in solving the weekly problems. Therefore, their variety and difficulty are a measure of the engineering ability that is both required and developed. For the purposes of discussion the types of problems assigned in the final two years of the course may be divided into several classes, although, with the exception of the first group discussed below, the problems will usually possess characteristics of two or more of the classes to be described.

The first class of problem is the academic type—given certain facts, to deduce certain relations, or prove other facts. This type of problem is one the student is used to solving from his college career. He finds the problem definite and knows that the answer can be found. Problems of this sort are assigned only occasionally as an exercise when a difficult and new concept is introduced; less than ten per cent of the assigned problems fall into this class.

A favorite type of problem, because of its frequent occurrence in practice and because it leads the student to fundamental thinking, is one that may be described as follows: An engineering design is to be attempted along conventional lines which are outlined to the student;

† "An Advanced Course in Engineering", A. R. Stevenson, Jr., and Alan Howard, ELECTRICAL ENGINEERING (AIEE TRANSACTIONS), March 1935.

Problems Encountered in Design	Theoretical Bases	Mathematical Tools
First year common to all sections		
	Mechanics	Differential equations
		Determinants
		Simultaneous linear equations
		Superposition
	Electricity and magnetism	Vector analysis
	Introduction to field theory	
	Elasticity	
	Waves and resonance	Fourier analysis
	Thermodynamics	Dimensional analysis
	Fluid flow	Functions of a complex variable
	Heat flow	
	Radiation	Operational methods
		Fourier integral
		Numerical integration
Second and third years in high-frequency section		
	Vibrating systems	Hamilton's principle and principle of least action
	Approximate methods for calculating resonant frequencies	LaGrange's equations
		Normal co-ordinates
	Hydrodynamics of sound	Review of vector analysis
	Equations of sound waves	Velocity potentials
	Reflection, absorption, attenuation, interference of waves	Solutions of wave equation
		Generalized curvilinear co-ordinates
	Radiation from various sound sources	Bessel functions
		Spherical harmonics
Horns	Physiological and psychological considerations in sound	
Loud speakers		
Microphones	Generalization of experimental laws of electricity and magnetism	
Sound measurement		
	Displacement current	
	Maxwell's equations	Scalar electric and vector magnetic potentials
	Static fields	Solutions of Laplace's and Poisson's equations
Electrostatic shields		Three-dimension flux plotting
	Varying fields in free space	
	Poynting's vector	Retarded potentials
Antennas	Electromagnetic radiation	Hertzian potential
	Electric waves in free space	
	Electric waves in ionized space	
	Electric waves over imperfect-conducting earth	
	Propagation characteristics of long and short waves	
	High-frequency resistance, inductance, and capacitance	
	Waves in and near conductors, guided waves	Solutions of "heat" or skin-effect equation
High-frequency shields	Maxwell's moving images	
Electrical measurements	Introduction to modern physics (radiation, spectra, thermionic emission, photoelectric effect, etc.)	
	Motion of electrons in electromagnetic fields	
Vacuum tubes	Space-charge theory, static and transit-time effects	
	Kinetic theory	
Gas-filled tubes	Conduction through gases	
Rectifiers	Noises in tubes	
	Coupled-circuit theory	
Amplifiers	Reactance theorems	
Feed-back circuits	Circuit theorems	
Oscillators	Four-terminal network theory	
	Introduction to synthesis methods	
	Conventional transmission line theory	
	Characteristics of amplitude, frequency, and phase-modulated waves	Series expansions with Bessel and other functions
Modulators and demodulators	Nonlinear circuits	
Radio transmitters	Distortion in tubes	
Radio receivers		
Applied optics	Geometrical optics	
	Physical optics	
Television devices	Electron optics	

however, because of certain unusual requirements it is feared that the usual type of design may not be satisfactory. For example, a connecting link is to be designed to operate between the antenna of a transmitter and the transmission line feeding it, and the student is acquainted with the usual type of design. In this case, however, the band width of frequencies to be passed is many times that which has ever been attempted with the common design. Should the design be altered or is it nevertheless satisfactory? Can an improved design more applicable to the wide band width be suggested? To deal with a problem of this type the student must ask such questions as: What constitutes a satisfactory connecting link? How does band width enter to determine the requirements of each part of the whole system and their matching? It would have been much easier for the student, had the problem been broken up into the finding of a frequency characteristic for each part of the system—a series of ordinary circuit or transmission-line analysis problems. Then, the student could have been given a series of rules determined by experienced designers by which he could ascertain whether the frequency characteristics indicate satisfactory or unsatisfactory design. But it is in the study of the bases for these rules that the student derives the training that will enable him to make original analyses in the future.

Many valuable problems come from the analyses of new inventions. Often an idea is suggested by analogy with a device in another branch of science or by certain physical considerations, and an analysis is required to determine whether the new idea is a workable one. In this case the student does not know beforehand whether the problem will require a long analytical study with many approximations, or whether the simple application of such tools as the conservation of energy and momentum or dimensional analysis may yield the necessary conclusion. One thing he is often certain of, however, is that the problem has not been solved before.

"When pupils get the notion that any field of study has been definitely surveyed, that knowledge about it is exhaustive and final, they may continue docile pupils, but they cease to be students."*

The largest group of problems are those in which an effect or characteristic is known to be present and the problem is that of obtaining quantitative data. These differ from the usual college problem in that in the first place many of them have never been solved before. The student does not have the assurance that by proper application of the material heard in the lecture the week before he is certain to obtain the result. The problem may not be exactly soluble. Almost always a number of approximations requiring a series of preliminary estimates have to be made. The student must decide whether to use a simple technique with additional computations intended to better the accuracy, or to approximate the problem by an exactly soluble mathematical counterpart for which a precise and elegant solution may be made.

Rotating Assignments

As was pointed out in the introduction, it is essential that the engineer (particularly in the high-frequency field) possess a balance in analytical and experimental

* From "How We Think" by John Dewey, pages 197 and 198.

ability, for one augments and enhances the other. To give this balance, during the second and third years of the course, the students are placed on assignment in various engineering departments of the company. Here they do regular engineering work varying from practice in standard design and manufacturing to research in the newest fields of radio. A good insight into the workings of a department is obtained during the assignment which may last for three or four months. (This period allows time for from six to eight assignments before completion of the course.)

Some of the assignments that the men in the high frequency section may have are as follows:

1. Design of radio and television transmitters and receivers.
2. Design of vacuum tubes.
3. Advanced development problems in radio and television.
4. Design and development of industrial control devices.
5. Design and development of gas-discharge devices of the power type.
6. Mathematical studies in the consulting departments.
7. Research in gas discharges, high-vacuum electronics, dielectrics, vibrations.
8. Research in electrical measurements.
9. District-office engineering, to obtain the customer's viewpoint.
10. Manufacture of radio receivers and vacuum tubes. A knowledge of factory processes and a real appreciation of the factors affecting cost are of prime interest to the radio engineer.

In these assignments, the men have proved so useful to departments in solving difficult problems and contributing new ideas, that the departments are glad to pay the men's salaries and often there are requests for students to fill assignments that must wait because of the limited number of students available.

Conclusions

Under this program, by the end of three years the men have received a thorough training in the fundamentals underlying electronics and high-frequency engineering. They have to a large degree learned how to use the analytical tools needed to apply the theory. It is comparatively easy for the graduate, when he is assigned to one particular phase of radio or television to go on by himself to master the special theory that applies. He is well acquainted with the problems and equipped to pursue their solution. Moreover he has obtained practical experience doing actual engineering work of varied types in regular departments alongside experienced men.

Discussion

H. W. Bibber (Ohio State University, Columbus): Stevenson and Ramo's paper will stimulate the thought of any teacher of electrical engineering who reads it with the problems of education in our field in the foreground of his mind.

To begin with, how is the student a few years out of college going to have the basic concepts in electricity which we gave him, widened in scope and extended to cover the ultrahigh frequencies which have now come on the scene? Here is a chance for the AIEE to help, by the publication in ELECTRICAL ENGINEERING of educational articles specially written for this purpose.

Next, the authors statements as to what the industrial practice of high-frequency engineering requires is very reassuring to teachers who have been advising students who wished to enter this field, to take graduate work with particular emphasis on mathematics and advanced physics. Only a small proportion of students interested in this field can hope to secure employment with a company that has a training course like the one described in this paper.

The quotation from John Dewey serves to remind college teachers of the necessity of continuing some organized laboratory work at the graduate level, in order that use may be made of principles set forth in lectures or in books, "in the recognition and solution of a problem". It is fortunate that high-frequency phenomena may be studied with laboratory equipment that is not beyond the means of the larger colleges to buy or build from parts. The same cannot be said of the study of power systems or large machinery. Postgraduate study while employed in industry has so many advantages that it is only fair to mention one which college postgraduate instruction possesses. That is the easy availability of laboratory facilities to students to settle immediately minor points that may arise in the solution of a major problem. If a student runs into a question of whether an assumption or simplification is justified during an evening's work on a long problem, he may try it out the next morning with a minimum of red tape in securing permission.

It is true that colleges tend to organize and co-ordinate their instruction with assigned problems in courses in order to give a student in a few months a knowledge of principles which it took earlier pioneers in the field many years to learn from haphazard experience. But they do recognize that at an advanced level it is essential for a student to work on problems of an original character, whether he has already mastered the theory necessary to their solution or not. The master's thesis and the doctor of philosophy dissertation are the academic answer to this necessity. A fair share of a graduate student's time is usually devoted to such work, and the award of an advanced degree is usually based on satisfactory demonstration of ability to think independently.

In speaking of ingenuity, the authors state that the colleges (especially in the undergraduate years) *have little time* to detect this ability, and in many other places throughout the paper there is either direct reference to the lack of time and crowding of the curriculum or inferences to the same effect. To speak of the area I know best, I must agree that the curriculum in the great state universities needs lengthening in time with only minor additions to content. If the pressure on our students could be relieved in part they might be encouraged to show inventiveness in their regular course work, or outside of it. They would have time to make use of shop privileges for constructing devices, privileges that I believe are widely offered but little used.

The extension of the curriculum to five years in the state universities should be just a reduction of the credit units per semester, and not a preliminary year (or two years!) of arts work before coming to engineering.

The authors properly place much stress on analysis as one of the desirable qualities to be sought for and developed in students. The counterpart of this quality they mention as "inventiveness," without stressing an educational point which I believe is important precisely in connection with high-frequency work. It is suggested by the item in their list of "theoretical bases" of course content entitled "Introduction to synthesis methods", which is probably intended to apply to synthesis of networks. Most teachers would agree that synthesis should have a far larger place in the scheme of engineering education than it does. It is certainly the fundamental psychological process involved in designing new equipment. Some training in it seems to come as a reflex from training in analysis, and in the machinery field it is difficult to carry out. Thus it would be impracticable to have each student make and put together the laminations, windings, shaft, and frame of a particular motor that he had designed.

But in the high-frequency field, laboratory work intended to develop synthesis is far more practicable. Electron tubes can be built by students themselves within a wide range of dimensions, and circuits built up from a stock of parts which are luckily not so expensive as to prevent a college laboratory from having enough on hand to supply its graduate students. It seems to me that it is in high-frequency work in colleges that synthesis as an intellectual process in electrical engineering may be taught to the extent that it can be taught at all.

A perusal of this paper serves to emphasize the enviable situation of students who secure employment with a big company that can afford to operate a training course —and has the vision to see its value to its future operations—such as that described. For those recent graduates employed in metropolitan districts, the evening courses at the graduate level recently started by some colleges, such as those in the New York City region, may serve as a partial substitute.

Ernst Weber (Polytechnic Institute of Brooklyn, Brooklyn, N. Y.): As the authors point out properly, the average four-year college program in electrical engineering cannot find time for "fundamental" courses, that is, courses which develop the prerequisite mathematical and physical concepts in a rigorous manner and show their applica-

Table I

Mathematical Tools	Basic Theory	Applications
Vector analysis (*M*)	Maxwell's field theory (*M*)	Power transmission and distribution
Functions of a complex variable (*M*)	Operational circuit analysis (*M*)	Advanced electrical machinery
Advanced differential equations (*D*)	Fundamentals of mechanics (*D*)	Network analysis
Higher mathematical analysis I	Fundamentals of radiation	Network synthesis
Matrix and tensor analysis	Fundamentals of electronics	Electronic tubes and circuits
	Statistical mechanics (*D*)	Higher mathematical analysis II
	Quantum mechanics	

tion in practical problems. One might perhaps refer to the usual undergraduate program as a first "sightseeing tour" to be followed in the postgraduate programs by real "exploration". In this sense, the outline offered by the authors is an excellent contribution from the point of view of industrial training courses and comes very close to our own graduate program except that we spend more time on the individual phases and use considerably more rigor in keeping with formal academic training. Thus, our program for the advanced degrees comprises essentially the individual courses listed in table I of this discussion and grouped in a manner similar to the authors' listing of topics, though not necessarily implying a definite sequence. The courses required of all students for the master's degree are marked (*M*), and those required additionally of all students for the doctor's degree are marked (*D*). For specialization in the field of power or communication engineering a sufficient choice of selective courses is available, including courses in other fields not listed in table I.

The similarity between the fundamental first year of the General Electric course and our required courses is striking, as is also the parallelism of the two years in the high-frequency section of General Electric and our own elective list for students specializing in communication engineering. This need not surprise one in view of the fact that most of our evening graduate students come from the research and development laboratories of the industrial and manufacturing companies of the metropolitan area of New York and, therefore, represent just as selected a group of interested and progressive young men as are admitted to the General Electric training-course program. In fact, our students usually bring with them a rich store of individual experience which makes teaching an enjoyable and gratifying activity. Again, as the authors point out, the success of such a fundamental program depends primarily upon the spirit in which it is carried on and that in turn has very much to do with the teachers of the courses. The great advantage of an industrial training program is the availability of nationally known experts in the particular subjects of study, but there is no reason why the same should not be true for the advanced courses in a well-organized graduate school. More and more emphasis is now given to the appointment of experts to teaching positions in the graduate divisions and to encouragement of industrial contact of teachers by means of conferences, of summer work, and of subsidized research. This is particularly true for our graduate division to which we also were able to attract eminent part time faculty members from the metropolitan industrial concerns. Thus, the old criticism that school training is dry and impractical can no longer be maintained with respect to a graduate program of the kind indicated above.

E. A. Guillemin (Massachusetts Institute of Technology, Cambridge, Mass.): The basic ideas set forth in the paper by Messrs. Stevenson and Ramo with regard to postgraduate work at the General Electric Company are unquestionably sound. They apply equally well, however, to the undergraduate curriculum where in fact it is essential to instill in the students' minds ideas which, even though they are elementary, are entirely consistent with the fundamental principles of electromagnetic theory to be developed later. It was this thought which motivated the rather comprehensive revision of the basic undergraduate curriculum for the electrical-engineering department of the Massachusetts Institute of Technology begun some nine years ago. The undergraduate work cannot be as comprehensive as the usual undergraduate plus graduate study, of course, but there is no reason why, by proper selection of material and form of presentation, the undergraduate work cannot provide a background which is thoroughly sound with regard to fundamental principles so that these need only to be amplified, and not discarded for lack of soundness, when the student proceeds to build upon them in his graduate study, whether this is done in college or carried on in connection with his practical work in industry. The very fact that the industry finds it necessary to give a graduate course of this nature indicates that the need for doing something of this sort in the undergraduate curricula (and perhaps in some graduate curricula) is not generally recognized.

As a specific example let us consider a semiqualitative discussion of the relation between field theory and circuit theory. One naturally cannot expect a sophomore to fully master the mathematical mechanism necessary for a complete discussion of this rather complex problem. On the other hand, it is entirely possible and appropriate to forewarn the student that the lumped circuit parameters (*R*, *L*, and *C*) as calculated by the ordinary engineering methods are merely approximations which are adequate for the lower-frequency ranges. Qualitative reasons for this can readily be given; it is even possible to derive rough criteria which show when and why the simple methods may be expected to fail. Even if this first presentation is not properly digested by the student, he has at least acquired an open mind on the question and need not suffer disillusionment later on in finding things to be only half true which he had always been led to understand were the whole and unshakable truth.

It is another principle in our scheme of undergraduate instruction that when a conception is sufficiently fundamental, though admittedly difficult to assimilate, a certain percentage can eventually be made to "stick" if brought to the student's attention in small doses at sufficiently frequent intervals. In our opinion it is definitely unsound to maintain that certain so-called "advanced" concepts are inappropriate for undergraduate instruction. A course of action based upon such a premise makes the shock fatal when the time comes to tell the truth.

Here at MIT, after a certain background for the relation between electromagnetic field theory and circuit theory has been laid in the sophomore work, the student is conditioned to a certain degree to receive a more substantial dose in a subject dealing with transmission line theory which is given to the seniors in the communications option. This subject is introduced by an elementary discussion of electromagnetic wave propagation—plane waves in free space, conductors, or semiconductors, surface waves and the accompanying phenomenon of skin effect. The theory of the radiating dipole and its application to antenna problems, which forms the concluding material in this subject, follows also quite logically from the same introductory discussion.

It is fully realized that only a few of the abler students get more than a moderate grasp of the more advanced portions of such a discussion. We have no illusions on this score. But we do feel that attempts of this nature are worth the time and effort. For if some of the men do continue in this field in their graduate work it will then be a third exposure for them and they should be in a position to accomplish something worthwhile, whereas a serious treatment of fundamental electromagnetic theory will still be just a play of symbols to them if it is their first exposure.

There is, of course, a certain amount of good judgment in postponing the presentation of material of a more special nature until the graduate year because of the fact that the average graduate class is a more select group of students from the standpoint both of ability and serious interest. However, it is also possible to inject into the undergraduate teaching procedure the necessary flexibility to make available to the student a variety of opportunities to suit the individual or group interests and abilities. The procedure of sectionalizing according to mental speed, the individual encouragement given the more able students, and the operation of the honors group system are methods which have proved useful toward making possible the differentiation in subject matter and in teaching procedure necessary for effectively carrying out a more ambitious program.

The comprehensive written and oral examinations given the honors group men in place of the ordinary term examinations provide original problems of a comprehensive nature (contributed by practicing engineers) requiring for their solution the initiative and perspective which Messrs. Stevenson and Ramo point out as being essential to the proper training of student engineers.

Finally I would like to state the opinion that graduate courses in the industry ex-

cepting those peculiar to a particular industry are fine for those students who cannot afford such study in college, but since this type of work is a side line for the industry it should follow that the college, whose primary responsibility is teaching, can do a better job of it. On the other hand it is clear that efforts of this sort on the part of the industry are bound to have beneficial effects, not only within their own group but also in academic circles because such activity cannot but stimulate thoughts along these lines by men having teaching responsibilities and thus lead them to make more constructive appraisals of their own efforts.

C. Francis Harding (Purdue University, Lafayette, Ind.): Although possibly directed more effectively to the selection of personnel for such an advanced course than to the content thereof, I would like to ask what credit and advancement are available in such a program for those who have secured their master of science or doctor of philosophy degrees in the graduate schools of universities and colleges? Although it has been stated that such courses in industry are not in competition with similar graduate courses in the universities, yet unless advanced students entering industry can capitalize upon such university graduate training the competition does really exist and the time is actually lengthened during which the new employee must remain in training before he is able to carry responsibility.

The five-year courses which are being considered at various universities and the relation of their resultant product to the regular four-year curriculum, plus a year's graduate course in industry, have been presented. The necessity for more time for assimilation of the curriculum and for thesis or other original work on the part of the undergraduate student has been emphasized. It may be of interest to note that Purdue University has just established two new five-year curricula in engineering to meet such needs. Curriculum *B* is identical in content, and in the bachelor of science degree granted, with the present curriculum *A* except that it is spread out over five years. Curriculum *C* contains approximately 24 credit hours of nontechnical subjects with the specification that there shall be included therein a minimum of three extra hours of economics, six hours of history and/or government, and six hours each of advanced mathematics and physics. The remainder of the extra credit hours are expected to include more of the humanities, English literature, and social sciences. The same bachelor of science degree is granted with certificated recognition of the extra work which has been accomplished. The minors of a master of science degree may also be satisfied in such a curriculum if the subjects are selected with proper care and approval.

These curricula should not be considered as replacing, in any sense, the present standard four-year engineering curricula. They are made available as substitutes for those interested in devoting more time to the securing of the bachelor of science degree or for those who wish to secure a broader cultural background for such a degree. They are not expected to decrease the interest in, nor the election of, the requirements for the more rigorous curricula leading to the master of science degree.

R. W. Sorensen (California Institute of Technology, Pasadena): If I were to apply the common critical methods of my occupation to this paper, I would begin by changing the title to the extent of eliminating the word "new", thus having the title read: "A Postgraduate Course in Industry in High-Frequency Engineering". I do this, because I am not acquainted with any other postgraduate course in high-frequency engineering and I would like to give full credit to the authors for their original, efficient, and complete way of laying the proper groundwork or foundation for a particular engineering activity incident to the work being done by the company by which the authors are employed. When many of us were young men just out of college, our training courses with industry were quite different. We took our place in the shop with the workmen and organized our own theoretical classes or seminars, if any.

As a college teacher, I am more than gratified to note the continued introduction of special advanced courses by industry to meet the needs which arise, particularly as these courses are of a type that not only supplements the work done by technical men in college, but continues to develop in these men, in parallel with their supplementary practical work, an interest and a facility in the theoretical and analytical aspects of the work they are doing.

The course under discussion is such that it could well be a regular graduate course given in an engineering college, and therein lies one danger which should be avoided. That is, I think colleges should not give courses of the type described, not because of lack of quality or trend of such courses, but rather because such courses are too specialized for a general course and hence are too specialized for college courses.

In fact, one of the authors of this paper and builders of the course described in the paper is a young man recently out of college who did not have such a course as a part of his college curriculum. Nevertheless, he has been able to plan and teach the course here outlined. He could do this, because he obtained a doctorate degree for the completion of a graduate course in electrical engineering, a considerable part of which comprised advanced courses in physics and mathematics, taught by the ablest of teachers and research men specializing in these subjects, rather than by engineers somewhat versed in mathematics and modern physics. Even as an undergraduate, the college course which the author had, provided some tools for doing work of the type described in this paper. As the use of one tool was mastered by Doctor Ramo other subjects listed as tools in this paper were added, very much in the order named, as his work continued throughout the graduate course.

In fact, about the only contribution which I see can be made to the paper by my discussion is to show that the course described is sound, because it provides the men taking the course with technical ability which will enable them to make analyses which keep pace with the developments that take place in this field in laboratory and shop. Also, it provides for a continuation of theoretical and analytical study by men who have been properly prepared for such work and thus further knits together our whole program of education in college and industry through a co-operative rather than a competitive program.

As long as colleges confine graduate work to equipping men with analytical tools rather than endeavoring to do things which naturally pertain to industry, in the way of developing designers, etc., and do not make graduate courses merely continuations of undergraduate work—just so long will our whole educational program be an efficient, co-operative one between the colleges on one side and industries on the other.

A. R. Stevenson, Jr., and **Simon Ramo**: It is reassuring to the authors to find their colleagues in the colleges, who are specialists in the field of engineering education, in general agreement as to the advisability of training along broad, fundamental lines in preparation for engineering work in high frequency and electronics.

The question has been raised as to what credit and advancement are available to students with advanced degrees in a program such as we have described. To answer this, it should first be pointed out that there is no "standardization" in the placing and developing of men in the General Electric Company. This applies also to the placing and training of men in our advanced course. Each man is considered as an individual case. We have had some doctors of philosophy whose ability and training were sufficiently removed from that which we try to develop in the course that they were not able to complete the work of the first year. Others have been given only one or two years of the three-year course and some have been given the job of supervising a year of the course which they did not take.

We like to have men with advanced training in our classes both as students and lecturers. We depend upon these men who come to us with new tools learned under skilled professors to add to our course ideas of which we might not otherwise be aware.

It has been stated in discussion that cooperation between industry and the colleges makes for the most efficient educational program. From our standpoint, this statement has already been borne out well by the discussions presented by the teaching profession; many ideas were put forth which will help us to improve our educational system and make the best use of the collegiate training of the student engineer.

Condensation of Mercury in Mercury-Arc Tubes

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Synopsis: It is found experimentally that the efficiency of condensation of mercury vapor on cold metal surfaces is quite low. The condensing efficiency of steel surfaces is increased several fold by positive-ion bombardment of the surface. Nickel surfaces condense mercury vapor several times as efficiently as steel. The operation of a high-voltage ignitron rectifier was greatly improved by positive-ion bombardment of the condensing surfaces.

IN mercury-arc power converting tubes, there is a continuous evolution of vapor from the mercury-pool cathode. This vapor is recondensed upon condensing surfaces which are kept cool by water, in larger tubes, and forced or natural circulation of air, in smaller tubes. The vapor density existing in a tube will then depend on the dynamic balance between the evolution at the cathode, and the removal of vapor by condensation at the condensing surfaces. It is well known that the successful operation of mercury-arc tubes is strongly dependent upon the vapor density being kept low, at least in the neighborhood of the anodes. If the temperature of the condensing surfaces is allowed to exceed 60 degrees centigrade, operation usually becomes unsatisfactory due to excessive frequency of arc back.

In estimating the vapor density which might exist in mercury-arc tubes, the authors, and probably also mercury-arc tube engineers generally, had not been seriously concerned about a possible low efficiency for condensation on the condensing surfaces. Elementary mechanical considerations lead them to believe that heavy mercury atoms, striking a surface made up of atoms not heavier than mercury atoms, should lose all their kinetic energy with no recoil, and come to rest on the surface. Thus, all mercury atoms reaching the surface should be condensed, with no direct reflection, and mercury atoms should leave the surface again only as re-evaporation. Because of the low temperature of the condensing surfaces, this re-evaporation is generally negligible.

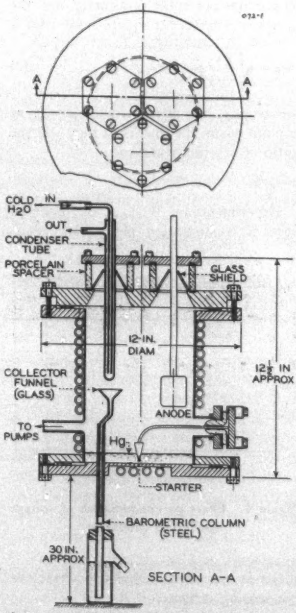

Figure 1. Mercury-condensation chamber

In estimating vapor densities, therefore, the authors never took into account a possible counterflow of molecules from the condensing surfaces, and it seemed that condensing surfaces generally used were sufficient to ensure a low vapor density at the anodes of tubes in operation.

It was a considerable shock, therefore, when Doctor R. C. Mason[1] called their attention to the fact that only for extremely clean condensing surfaces is the direct reflection of mercury atoms negligible, and that slight contamination, quite unavoidable in practical tubes, would reduce the condensing efficiency to very low values. This phenomenon has been known a long time to physicists,[2] but its significance seems not to have been appreciated by engineers.

It seemed desirable then to make a direct study of the efficiency of condensation of mercury on various surfaces under conditions similar to those existing in practical operating mercury-arc steel tanks. Also, it was desired to check the idea that continuous positive-ion bombardment might keep condensing surfaces sufficiently free from contamination that their condensing efficiency might be kept high.

Apparatus

The apparatus in figure 1 was built around an experimental ignitron tank as a foundation. The coils which are soldered to the sides and bottom of the tank were connected so as to form a closed circulating system with a water pump, electric water heater, and a thermostat. Thus, the temperature of the mercury in the bottom of the tank was known to the accuracy of the operation of the thermostat, which was plus or minus one-half degree centigrade. The special top plate, with provisions for three small electrodes was made for this experiment. The three electrodes were insulated from the rest of the apparatus by the porcelain spacers; the bolts which held them in place were insulated from the electrodes by Micarta bushings. Two of the electrodes were of the shape and size of the one shown on the left, while the third was an "anode," as shown on the right. Glass funnels under each of the two similar electrodes conducted the mercury which condensed on to and fell from the condensing tubes to the two barometric columns. Mercury so collected was drained from the barometric columns and weighed at suitable intervals. Readings taken in this manner had no effect on the conditions within the chamber. The third electrode, as shown, was used as an anode when it was desired to run an arc in the chamber, simulating conditions in an ignitron. Tap water was used to cool the condensing tubes. Seasonal fluctuation caused the temperature of the tap water to vary between 10 and 25 degrees centigrade. The vapor pressure of mercury in equilibrium with condensed mercury in this temperature range is low in comparison with that at 60 degrees centigrade, as the pressure doubles for each 10-degree rise in temperature in this range.

Paper 40-72, recommended by the AIEE subcommittee on electronics, and presented at the AIEE winter convention, New York, N. Y., January 22-26, 1940. Manuscript submitted November 6, 1939; made available for preprinting January 2, 1940; released for final publication February 23, 1940.

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1. For all numbered references, see list at end of paper.

Calculation of Efficiency From Observed Condensation

Besides directly investigating the relative yields of condensed mercury from various surfaces under different conditions, it is desirable to make an estimate of the efficiency, or condensation, coefficient. This coefficient may be defined as the number of molecules condensing divided by the number of molecules striking the surface. If the area under consideration is a condensing surface of extremely poor efficiency, so that there is no appreciable flow, a formula from simple kinetic theory may be used to compute the number of molecules which strike the surface per second. At the other extreme, a surface of 100 per cent condensing efficiency appears to the condensing vapor as a hole into a completely evacuated chamber. In this case, the vapor at the condensing surface is in a state of flow, and its density and temperature are different from that of the vapor at rest far from the surface. We may calculate what this flow will be by using the mathematical theory of the mechanics of continuous fluids, although we must recognize that at the condensing surface this theory fails to be applicable, since the vapor there, with its non-Maxwellian distribution of molecular velocities, cannot be said to have a scalar pressure and temperature as contemplated in fluid mechanical theory. However, this theory should be applicable up to within a few molecular mean free paths from the surface. We may then attempt to modify the simple kinetic-theory formula, by taking into account the flow and the altered density and temperature predicted by the continuous-fluid mechanical theory.

Kinetic theory gives v the number of molecules crossing from one side to the other side of a unit surface in unit time in a gas in equilibrium as

$$v = {}^1/_4 N\bar{c}$$

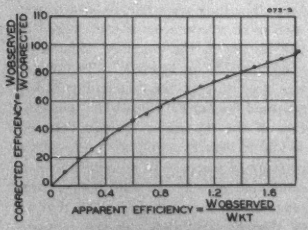

Figure 2. Calculated efficiency as function of observed yield

where N is the number of molecules per unit volume, and $\bar{c}$ is the mean velocity of thermal motion. The weight in grams of these molecules is

$$W_{kT} = p\sqrt{\frac{M}{2\pi RT}} = 43.7\times10^{-4}p\sqrt{\frac{M}{T}} \qquad (1)$$

where p is the pressure, dynes per square centimeter, M the molecular weight, T the absolute temperature in degrees Kelvin, R the gas constant in ergs per degree, and the units of area and time are the square centimeter and second.

From the mechanics of continuous fluids the mass of a perfect gas flowing per second across an area of one square centimeter at a point where the density is ρ grams per cubic centimeter, and the pressure p dynes per square centimeter is

$$W_H = \sqrt{\frac{2\gamma}{\gamma-1}}\, p_0\rho_0\left\{x^2 - x^{\gamma+1}\right\} \qquad (2)$$

where p_0,ρ_0 are pressure and density at a point where the fluid is at rest, γ is the ratio of specific heats and

$$x = p/p_0$$

Experimentally, $W_{observed}$, the observed rate of condensation per square centimeter is measured. Obviously, near the condensing surface

$$W_{obs} = V\rho = Vx\rho_0 \qquad (3)$$

where V = mean or hydrodynamical velocity of motion of the gas toward the condensing surface. Assume that the molecules of the gas have a Maxwellian distribution of velocities about a set of axes moving toward the surface with the velocity V, although as mentioned before, this cannot be true within a mean free path of the condensing surface. From equations 2 and 3, we calculate V and x. We then return to (1) and modify it to obtain an expression for the number of molecules striking the surface in terms of the pressure and temperature of the vapor in regions unaffected by the condensation, and where it is at rest, taking into account the effect of the hydromechanical motion corresponding to the observed rate of condensation. Equation 1 is derived by integrating

$$\rho\int_0^\infty uf(u)du$$

where $f(u)$ is the Maxwellian distribution function for the velocities in a direction perpendicular to the area. If the body of the gas or vapor is approaching the surface with a velocity V, the distribution function will be $f(u-V)$. As we are

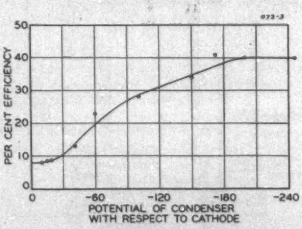

Figure 3. Effect on condensation of voltage applied to condenser

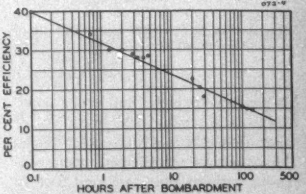

Figure 4. Decrease of condensing efficiency with time after bombardment

interested in knowing how these conditions deviate from those in our first equation, we let

$$R = \frac{\int_0^\infty uf(u-V)du}{\int_0^\infty uf(u)du}$$

$$= e^{-\left(\frac{V}{\alpha}\right)^2} + \sqrt{\pi}\frac{V}{\alpha}\left[1+P\left(\frac{V}{\alpha}\right)\right]$$

where $P(y)$ is the probability integral

$$P(y) = \frac{2}{\sqrt{\pi}}\int_0^y e^{-y^2}dy$$

and α is the most probable molecular velocity. Thus, equation 1 should be multiplied by R to allow for the motion of the vapor toward the condensing surface.

As the gas moves toward the condensing surface, it undergoes an adiabatic expansion. The changes in p and T from the equation of state of a perfect gas are given by

$$x = \frac{\rho}{\rho_0} = \left(\frac{p}{p_0}\right)^{\frac{1}{\gamma}} = \left(\frac{T}{T_0}\right)^{\frac{1}{\gamma-1}}$$

where γ is the ratio of the specific heats which for mercury vapor is 1.66. Hence, equation 1 will need to be modified to allow for this changed density and temperature by multiplying by $x^{\frac{\gamma+1}{2}}$. The

value of α in the correcting factor R, is also a function of x.

Combining all of these correcting factors, we obtain for calculated mass of molecules striking a centimeter square of area of condenser per second,

$$W_{\text{corrected}} = W_{kT} x \frac{\gamma+1}{2} R$$

$$= A(M, p_0, T_0, \rho_0, \alpha_0) F(W_{\text{obs}}) \quad (4)$$

where A is a function of the conditions existing in the vapor at parts unaffected by the presence of the condensing surface.

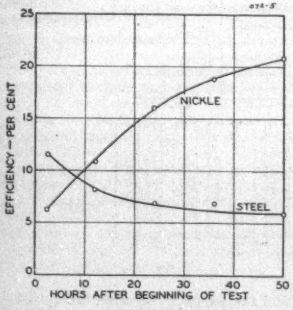

Figure 5. Efficiencies of condensers during a test

The corrected efficiency $W_{\text{observed}} \div W_{\text{corrected}}$, can then be calculated from the apparent efficiency, $W_{\text{observed}}/W_{kT}$. A curve of corrected efficiency is plotted against apparent efficiency in figure 2. The data in this paper are expressed in terms of the corrected efficiencies as taken from figure 2.

Experimental Results

With the temperature of the condensed mercury 60 degrees, and that of the condensing surfaces 10 to 25 degrees centigrade, the efficiency of condensation of mercury vapor on freshly sand-blasted steel electrodes is found to vary between 1.5 per cent and 8 per cent. This variation is attributed to different surface conditions.

Surfaces which have been roughened with coarse alundum cloth and washed in alcohol or benzene give results similar to sand-blasted surfaces, as do freshly machined (rough lathe turned) steel surfaces. We found no treatment of a steel surface, prior to its insertion into the vacuum chamber, which would cause its efficiency of condensation to be higher than that of a sand-blasted surface.

To simulate conditions existing in an ignitron, the third electrode (on the right in figure 1) was used as an anode, and an average current of 15 to 50 amperes was passed through the tube when it was being used as a half-wave rectifier feeding a resistance load from a 220-volt a-c power source. It was found that the yield obtained from the condensing tubes during alternate one-hour periods when a 15-ampere arc was run in the chamber was 20 per cent higher than that observed during the interspersed one-hour periods when no arc was run. This was taken as an indication that the presence of the arc raised the pressure of the mercury vapor in the tube by 20 per cent.

Effect of Negative Voltage Applied to Condensing Surface

The application of a negative potential, with respect to the cathode, to the condensing tube is believed to cause it to be surrounded by a positive-ion sheath during the conducting half cycle. The thickness of the sheath, according to Langmuir's theory of currents to a probe in a plasma, is small in comparison to the diameter of the condensing tube. Positively charged mercury ions then will fall through the sheath and bombard the condensing surface with an energy which is proportional to the potential difference between the arc plasma and the condensing tube. The positive-ion current collected by the condensing tube does not vary as the negative potential of the tube is increased, which is as should be expected if the thickness of the positive-ion sheath remains small, since this current is determined by the random positive-ion current density in the plasma, and all of the positive ions which come to the sheath are drawn to the condensing tube.

The bombardment of the condensing surface by positive ions has a remarkable effect on its efficiency of condensation. The manner in which the efficiency increased as the negative potential was increased is shown in figure 3. These data have been corrected for the increase in mercury-vapor pressure caused by running the arc, as explained earlier. The observed increase in efficiency cannot be explained by the simple collection of positively charged molecules, since the current drawn by the condensing tube and the amount of condensation are of such magnitude that there are of the order of 1,000 mercury atoms collected for each positive charge. Hence, we must conclude that the positive-ion bombardment so alters the condensing surface as to increase its efficiency for the condensation of neutral molecules. The efficiency of the condensing surface as a function of time after the arc is turned off is shown in figure 4. The rate at which the efficiency decreases, as well as the value it reaches in a given time, is a function of the length of the preceding bombarding period; if the bombardment has been for a few hours instead of several days, as it was before the data of figure 4 were taken, the efficiency returns to its initial value of less than ten per cent in less than a day.

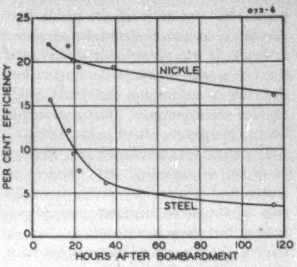

Figure 6. Decay in efficiency after stopping positive-ion bombardment

Condensation on Nickel

The condensation of mercury on a nickel surface was also investigated. One of the steel electrodes shown in figure 1 was replaced by a similar one made of nickel, and in this manner the behavior of the two surfaces was compared under identical conditions. The interesting difference in the rate at which mercury condenses on the two surfaces is shown in figure 5. In this instance, the steel electrode had been bombarded by positive ions before the nickel electrode was placed in the chamber. No arc was run after the insertion of the nickel electrode. The yield from the steel electrode declined as in figure 4, but the yield from the freshly sand-blasted nickel electrode increased during the same interval of time.

When the nickel and steel electrodes are bombarded by positive ions, the maximum yield obtainable from each is similar. After the arc was turned off, the yields from the two electrodes decreased as shown in figure 6.

When two freshly sand-blasted electrodes, one steel and one nickel, were placed in the evacuated chamber and a temperature difference between the mercury pool and the electrodes maintained, the interesting curves of figure 7*a* were obtained. The absolute yields show large fluctuations during the month

period, but the ratio of the yields from the nickel and steel electrodes as shown in figure 7*b* was remarkably steady after the first week. Some of the fluctuations were due to a change in the steady conditions of the experiment during weekends. These changes are noted in the figure.

The much greater condensing efficiency of nickel as compared with steel is remarkable. The initial yields from the two sand-blasted surfaces are always similar, but the rate with which the yield from a nickel surface improves did vary. Thus, as shown in figure 5, the improvement was more rapid than in figure 7*a*. Apparently the rate of improvement depends on the time between sand blasting and the setting up of a temperature difference for condensation.

Effect of Electric Excitation of Condensing Surfaces in Operating Rectifiers

Some preliminary tests were made to determine whether improving the condensing efficiency by positive-ion bombardment of condensing surfaces would give any improvement in performance of operating rectifiers. For these tests

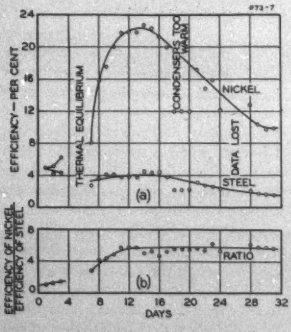

Figure 7. Comparison of nickel and steel condensers over 30 days

we used a pair of ignitrons as a full-wave rectifier, feeding into a resistance load at 8,000 volts direct current. During the greater part of the test, the load current was maintained at 25 amperes, and the condensing surfaces were energized on alternate one- or two-day periods, unenergized on the intervening periods. The number and distribution of observed arc backs are shown in figure 8*a*. The arc backs appear to occur at random during both the energized and unenergized periods. The average number of arc backs per hour was 0.862 and 0.08, a reduction of more than ten by the application of potential to the condensing surfaces.

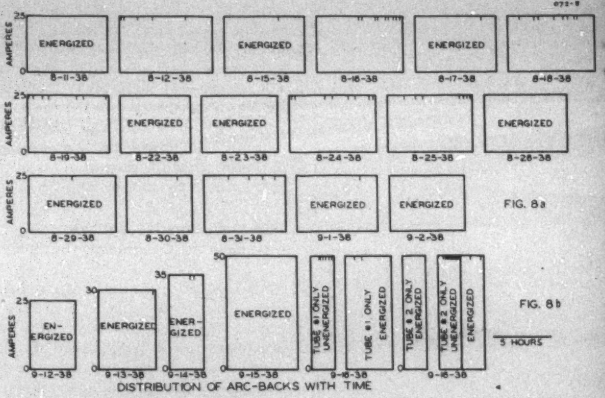

Figure 8. Plot of arc-backs observed with two ignitrons feeding an 8,000-volt 25- to 50-ampere resistance load

Arc-backs indicated in figure 8*a* are for either tube, those in figure 8*b* are for the individual tubes

The first part of the test was concluded by the failure of the mechanical vacuum pump. After the ignitrons had again been treated out, a short test was made at higher currents, to 50 amperes. The data of this test are shown in figure 8*b*. An entire day without a failure was obtained while the condensing surfaces were energized on September 15. The next day the surfaces of one tube at a time were de-energized, and the data for the two tubes are shown separately. Both tubes operated satisfactorily for a while, but the one whose condensing surface was de-energized soon began to fail. Tube 2, when de-energized, ultimately became so bad that it would not carry the load for as long as one minute. When the surface was energized, it failed only twice in the following two hours. This complete failure to carry the greater load of 50 amperes when the surfaces were not energized, and the immediate ability to operate satisfactorily when the surfaces were energized were verified by data similar to that in figure 8*b* several times.

However, when the tubes were being operated at 3,000 volts direct current, and the arc backs occurred infrequently, no definite improvement was obtained by the application of potential to the condensing surfaces. Similar tests on larger ignitrons at 600 volts also failed to show conclusively that arc backs were reduced in number by improved condensation.

Summary and Conclusion

1. Very low condensing efficiencies for mercury usually less than ten per cent were found for water-cooled steel surfaces under conditions simulating those obtaining in practical steel-tank rectifiers.

2. Positive-ion bombardment of condensing surfaces caused a great increase in their condensing efficiency.

3. Nickel surfaces usually showed a condensing efficiency several times as large as for steel surfaces.

4. Positive-ion bombardment of the condensing surfaces of an 8,000-volt d-c 25-ampere single-phase ignitron rectifier greatly improved its operating performance. Similar treatment of a 3,000-volt 200-ampere single-phase ignitron, however, gave no improvement in performance.

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Electric Power for Airplanes

W. J. CLARDY
MEMBER AIEE

Synopsis: Electric-power loads are increasing rapidly on airplanes and auxiliary-engine-driven generators offer dependable power sources independent of main engines. Minimum weight for the required capacity is essential in the design of generators, motors, and control. The a-c 110-volt 400-cycle three-phase system has been developed for large airplanes with heavy motor loads. Alternators rating 12.5 kva at 75 per cent power factor and two-pole motors running at 22,500 rpm full-load speed are available. Control apparatus builds up the alternator, establishes accurate voltage regulation, and provides direct current for excitation and battery charging. The 24-volt system is applied on airplanes using d-c power which have relatively light motor loads. Generators rate 5 kw and are designed for speeds ranging from 3,200 to 6,000 rpm to conform to prime-mover requirements. Motors have been built which run at 7,500 rpm. The control effectively regulates the voltage, handles battery charging, and provides for starting the power plant.

Featherweight Electrical Apparatus

AN engineer intently watches the speeding motor shaft—so fast that it is just a blur to the eye. The light of the stroboscope is turned on it and the shaft is seen stationary. The surface of the small 22,500-rpm rotor of the six-horsepower motor travels the distance from New York to Chicago in less than four hours. This is one of the impressive electrical developments for airplanes wherein speed goes up and weight comes down. There is an insistent demand to save "pounds" in aircraft electrical equipment and thus increase "pay-load" capacity. Featherweight generators, motors, and control are now available for such applications.

Airplane Electric-Power Problems

The growth of electric-power loads on airplanes coincides with increases in size, speed, and flying range. Aircraft developments have been extensive during the past few years, resulting in substantial boosts in the uses of electrical energy. Small 6- or 12-volt d-c automotive-type generators, either main-engine driven or located in the air stream, have long served as power sources. These low-voltage systems are inadequate for modern airplanes because of low weight efficiency. It is necessary to apply large generators operating at relatively high voltage to assure economic installations. The result has been the development of the auxiliary-engine-driven power plant, trial of the five-kw main-engine-driven generators, and investigation of steam, hydraulic, and exhaust gas turbines as prime movers.

Figure 1. Aircraft alternator

This is a 400-cycle three-phase machine and is rated 12.5 kw, 120 volts at 75 per cent power factor. It weighs close to 100 pounds

The auxiliary-engine-driven generator offers a satisfactory means of power supply, continuously available under all operating conditions, independent of the main engine. Units are designed to secure minimum weight for a specific flight time. This requires consideration of the weight of the fuel, oil, engine, generator, and control as well as the efficiency of the plant. Low fuel and oil consumption, which means high engine efficiency, are pertinent in equalizing the weight of fuel and oil with that of the engine. The generator requires the same consideration. A balance must be reached for generator active parts in comparison with fuel and oil weight for a given flight period.

Motors are being extensively used to perform various functions on airplanes. Light weight is essential and in this case, efficiency, the duty cycle, and ventilation affect design. Here again, efficiency has a bearing on the power used and can be evaluated in terms of fuel and oil weight. However, the duty cycle is a factor since high efficiency becomes progressively more important in terms of fuel and oil weight for momentary, intermittent, and continuous operation. Motor weight will go up with decreased ventilation which makes it desirable to limit the use of explosion-proof and enclosed types.

110-Volt A-C System

The 110-volt 400-cycle three-phase a-c system is applicable to large aircraft. Alternators have been built and tested which are rated 12.5 kva at 120 volts and 75 per cent power factor, and weigh practically 100 pounds. The machines operate at 3,430 rpm, a speed which is fixed by the prime mover. Rotors have 14 poles and are mounted on engine-shaft extensions to eliminate bearings. The same shaft extension carries a propeller-type fan which provides additional flywheel effect, cools the engine, and ventilates the alternator. Stators are attached directly to engines.

Alternator efficiency is 92 per cent, a figure selected after an analysis of the weight of the complete power plant plus fuel and oil. Above 92 per cent efficiency,

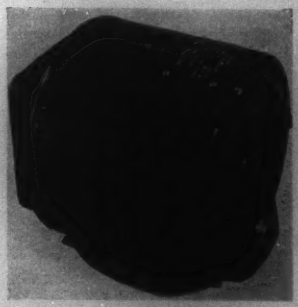

Figure 2. A 400-cycle three-phase a-c aircraft motor

This machine is rated six horsepower at 110 volts and weighs slightly over 15 pounds. When operating at full load the speed is 22,500 rpm

Paper 40-24, recommended by the AIEE committee on transportation, and presented at the AIEE winter convention, New York, N. Y., January 22-26, 1940. Manuscript submitted November 9, 1939; made available for preprinting December 12, 1939; released for final publication March 2, 1940.

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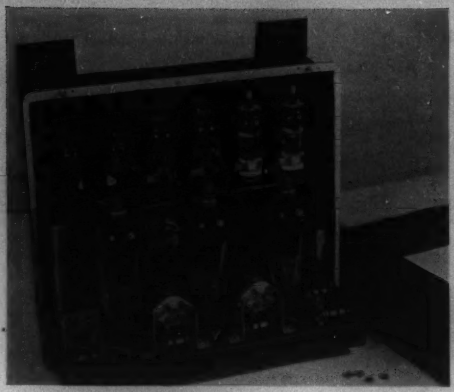

Figure 3. Aircraft electronic voltage regulator used with the 110-volt 400-cycle three-phase a-c system

This device regulates the voltage of each of the three phases and accurately maintains the bus potential

Figure 4. Aircraft battery charger for the 110-volt 400-cycle three-phase a-c system

This dry plate type rectifier furnishes either 14 or 28 volts direct current for battery charging and the operation of d-c auxiliaries

the increase in alternator active parts balances the fuel and oil weight reduction for a 40-hour flight. Overload capacity is determined by sudden load changes, such as may occur with the starting of large induction motors. This is particularly true if the lights and continuous-running motors are operating and momentary starting loads are applied. This condition may reduce voltage too much and consequently alternators are designed for high current overload capacities at low power factors.

Lightweight high-speed induction motors are well suited for 400-cycle three-phase operation. A wide speed range is obtainable by varying the number of poles and machines have been designed to meet many different requirements. Some applications demand high torques for momentary or intermittent use, while others need high efficiency for continuous operation. Two-pole machines have a synchronous speed of 24,000 rpm and normally operate at 22,500 rpm when fully loaded. The larger sizes develop double full-load torque with 3 to $3^1/_2$ times full-load current.

The control regulates the a-c power supply, furnishes 14 or 28 volts direct current for battery charging and d-c auxiliaries, establishes satisfactory parallel operation, and practically eliminates radio or audio interference. The electronic voltage regulator, which has been developed, is faster in response than the mechanical type. Simpler and more positive antihunting methods are obtainable for less weight. It is both a regulator and exciter in one device since d-c field power is provided by rectification from the a-c bus. The regulating tubes are in duplicate to assure reliability. An intermittent-rated Rectox and transformer cause the alternator to build up from its residual magnetism. This function is under the control of a small "Silverstat" regulator which corrects for temperature variations in the circuit resistance. The transfer to electronic regulation is automatic by means of a small thermal timing relay. This method of initial build-up is necessary since sufficient time must elapse for the electronic regulator tubes to reach operating temperature before field current is obtained by rectification.

The engine driving an alternator is started and automatically idled until it reaches operating temperature after which it comes up to normal speed. The alternator switch is then manually placed in the "build-up" position and the voltage rises to normal value under self-excitation and magnetic voltage-regulator control. After some 45 seconds, during which the filaments of the electronic regulator have reached normal operating temperature, the alternator control switch automatically trips to the "run" position. The machine is then under electronic regulation and may be connected to the main bus by closing a circuit breaker. When a second unit is started and is under electronic regulation it may be connected to the bus by closing the circuit breaker. If a reversal of power occurs manual-reset wattmeter contacts function to disconnect the alternator from the bus.

The battery-charging unit consists of a dry-plate rectifier fed from a three-phase transformer through a tap-changing device under control of a mechanical voltage regulator. The rectified voltage is maintained practically constant regardless of load and ambient temperature changes. A central control station contains the alternator circuit breakers, the manually operated build-up switch, and necessary metering equipment.

Figure 5. The aircraft control station contains all the necessary instruments and switches for the operation of two 110-volt 400-cycle three-phase a-c power plants

The 110-volt 400-cycle three-phase system is suitable for lightweight radio equipment and is practical for three-phase induction motors. The use of three wires in conduits, together with the

Figure 6. This 4,000-rpm aircraft generator is rated 5 kw, 28.5 volts, 175 amperes. It has a five-minute rating of 7.5 kw. The total weight including the starting switch is just over 50 pounds

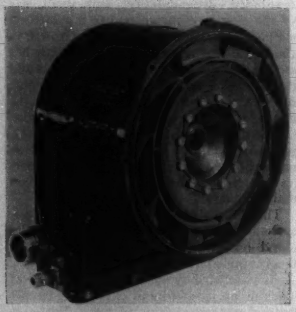

Figure 7. This aircraft generator is in the featherweight class and weighs slightly over 40 pounds including the starting switch. It is rated 5 kw, 28.5 volts, 175 amperes, and will carry 7.5 kw for five minutes. It runs at 6,000 rpm

Figure 8 (left). This aircraft generator runs at 3,200 rpm and weighs just under 70 pounds including the starting switch. It is rated 5 kw, 28.5 volts, 175 amperes, and will carry 6½ kw for 15 minutes

proper balance of single-phase loads between the three phases, avoids the impedance drops which occur with single phase. Motors will start and produce rated outputs without the use of centrifugal switches, external capacitors, and other control devices. Thus, the system is well adapted for application on large airplanes which make extensive use of electric power and have heavy motor loads.

24-Volt D-C System

The 24-volt system is becoming a standard on airplanes using d-c auxiliary power. Generators have been built which are rated five kw, 28.5 volts, 175 amperes and will carry short-time overloads of 150 per cent normal capacity. Operating speeds are 3,200, 3,430, 4,000, and 6,000 rpm and are determined by the available prime movers. In the case of the 6,000-rpm machine the engine runs at 3,000 rpm. Machines are designed with magnesium-alloy supporting brackets and housings to assure light weight. Fans are magnesium, aluminum, or a heavier metal depending on the added flywheel effect needed for the engine when the armature weight is insufficient. The effectiveness of this weight varies directly as the square of the radius and the fan is the largest-radius rotating member. Special iron alloys are used for the magnetic circuit. Insulation is composed entirely of glass, mica, and asbestos. Generator armatures and fans are mounted on shaft extensions and stators are bolted directly to engines.

It appears that motor speeds will remain at or below 10,000 rpm. The inherent limitations of armature construction and the high starting torques required tend to limit maximum speeds. Motors which have been built run at 7,500 rpm as compared with the much higher speeds practicable with a-c induction types. The materials used and the insulation are essentially the same as for generators.

The control regulates the d-c power supply and furnishes charging current for a small battery. It automatically disconnects the battery when the power plant is shut down and functions with little radio or audio interference. The voltage regulator is a small lightweight device utilizing a modification of the industrial Silverstat. Contact maintenance is practically eliminated by distributing the regulating duty over 15 to 20 contacts, each operating safely below the "sparking voltage". Rocking-type bearings, spring restrained, minimize friction and wear.

Change in regulated voltage during the warm-up period has been reduced by using low-temperature-coefficient wire in the regulator coil. Correction for ambient-temperature variation is provided by bimetal compensation of the calibrating-spring tension. The ratio of battery capacity to that of the generator is small, which makes it necessary that the reverse-current device drop out at a small current

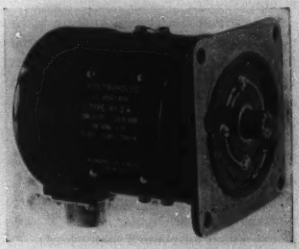

Figure 9. This aircraft motor develops five-eighths horsepower at 25 volts and 7,500 rpm. It weighs close to seven pounds complete

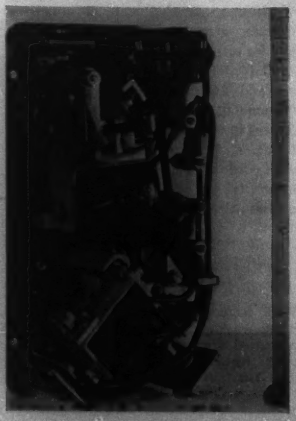

Figure 10(right). This aircraft voltage regulator and reverse-current switch is applicable to the 12-volt d-c system

It weighs under four pounds and maintains accurately regulated bus voltage for 15-volt main-engine-driven aircraft generators

Figure 11. This aircraft voltage regulator and reverse-current relay handles the 24-volt d-c system

It maintains 28.5 volts at the bus. The complete weight including cover is less than nine pounds

value. The relay closes when generator voltage is one volt above battery voltage and opens on less than ten amperes reverse current. It operates the generator contactor which has silver contacts of adequate capacity to handle 175 amperes rated current. By using the generator as a motor to start the engine there is no need for a separate starting motor and its coupling. This combination of functions reduces equipment and cable weights since a separate heavy starting-motor circuit is unnecessary.

The 24-volt d-c system appears to be best for standardizing on one potential for a number of different sized airplanes. It is possible to handle readily battery charging without upsetting present standards. Two 12-volt batteries are applicable, thus facilitating changing from 12 to 24 volts by having 12 volts available during the changeover period. The 24-volt system can be employed advantageously on the lighter types of airplanes which have small motor loads.

New A-C and D-C Apparatus Available

The past 18 months has been a period of intense development of auxiliary engines, generators, motors, and control for airplanes. The two systems now available—110-volt 400-cycle three-phase a-c and 24-volt d-c—meet present requirements and provide for future increases in the use of electric power. The former is well suited for large airplanes with predominating motor loads and the latter is an applicable standard for medium-sized craft with light motor loads.

Discussion

V. H. Grant (United States Navy Department, Washington, D. C.): Mr. Clardy has presented some interesting points on a-c power for aircraft. The Navy, having at least as extensive and complex aircraft electrical systems as exist today, has been undertaking a comprehensive research program on electric power for airplanes. Our results to date do not check entirely with Mr. Clardy's analysis, and a brief summary of our points of difference may be of interest.

First, auxiliary engines for driving generators are extremely expensive, as compared to main-engine drive, in reduced airplane performance and lower useful or pay load. An analysis which we made recently indicates that a 50,000-pound plane suffers less loss in performance by diverting 50 horsepower for auxiliaries from the main engines than in carrying additional auxiliary engines and the extra fuel and oil which they require.

Second, a twin-engine airplane with two auxiliary engines is actually a four-engine plane, insofar as maintenance and overhaul are concerned. The small engines are almost as complex to overhaul as are main engines.

Third, valuable space in the plane must be appropriated, and made soundproof and fireproof, for auxiliary engines.

Fourth, auxiliary engines present an unnecessary additional target, in the case of military planes.

True, main engines are "cleaned up" by the use of auxiliary engines, and a constant drive speed is obtained, permitting the use of a-c generators but these advantages are gained at a considerable penalty. And, whether we want alternating current after we have provided for its generation is questionable, at least for our peculiar requirements. Some of the arguments on this matter may be summarized as follows:

1. Practically all our motors are of the momentary-duty type, requiring high starting torque; they are designed on the basis of torque rather than heating. A d-c series motor is ideal for this service.

2. D-c generators use simple regulators and may be paralleled easily.

3. Battery stand-by may be used for vital services and for peak loads.

4. Much of our load, if alternating current, would be operated from a single-phase source. Load balancing during emergency operation would probably keep the poor flight engineer too busy to do anything else.

5. Voltage diversity would be simplified, but, to date, radio equipment, the only load requiring voltage change, cannot be operated in parallel with fluctuating power loads, owing to the light weight master oscillator circuits being very critical of supply voltage.

6. High-speed motors, although very light in weight, require gear reducers of considerable weight to provide usable speeds. Starting these motors with their low torque, at low temperatures with the gear box grease congealed, may be a problem. Also, the matter of bearing design and lubrication is by no means solved.

7. Conductor weights are smaller with direct current due to fewer wires, and to the absence of the power-factor problem; the power factor of an induction motor when starting is notoriously low.

Mr. Clardy has mentioned high efficiency of equipment. Our studies, so far, indicate that generators, conductors, motors, etc., should have just about as low efficiencies as possible without burning up. The reason is, of course, the weight saving possible by "forcing" the equipment far beyond its maximum efficiency. Weight, in general, appears to be more important in determining airplane performance than power input.

It is the intent of my remarks to promote further discussion and thought on this matter, which is by no means settled. The Navy will benefit as much as anybody from the final solution to the aircraft auxiliary-power problem, and will appreciate any other remarks.

W. J. Clardy: Aircraft auxiliary-engine-driven power plants appear essential for ground or sea-level service in order to avoid main-engine operation for furnishing auxiliary power. Increase in the use of such units will, naturally, lead to improvements to give better weight efficiency. The accessibility, dependability, and small size of the auxiliary engine makes it relatively simple to inspect and maintain. Growth in the use of electric power on airplanes has stepped-up generator sizes. Gear boxes and drive shafts are needed for main-engine drives and the mechanical problems become acute in the case of large units. A main-engine-driven generator, drive shaft, and gear box should be just as good a target as an auxiliary-engine-driven generator—perhaps better since fire may be concentrated on main engines.

The 110-volt 400-cycle three-phase a-c system has been developed to meet the demand for more power—10, 12.5, and 20 kva in single power plants. Alternators are easily paralleled by merely bringing a second machine up to speed and closing the circuit breaker to connect it to the line. Batteries and battery chargers are used with the a-c system but it seems desirable to keep such heavy power sources to a minimum in the interest of weight economy. The proper balancing of single-phase loads can be worked out in advance of any emergency. It is entirely practicable to build light-weight radio equipment for the 110-volt 400-cycle three-phase system and voltage regulation is extremely accurate.

Light-weight high-speed induction motors are well adapted for 400-cycle three-phase operation. High starting torques are obtainable and alternators are designed for high current overloads at lowered power factors to avoid impairment of voltage regulation. Two-pole induction motors run at 24,000 rpm synchronous speed. Lower speeds are secured by increasing the number of poles. In a weight analysis it is necessary to include gearing required for a motor but even on this basis high speed is advantageous. This seems to be borne out by the universal trend to higher speeds. A lubrication system has been evolved for 24,000-rpm motors which appears to be satisfactory under all service temperature conditions.

An airplane with an extensive motor load requires high voltage to avoid exces-

Some Impulse-Voltage Breakdown Tests on Oil-Treated Paper-Insulated Cables

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J. A. SCOTT
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Synopsis: Data are presented on impulse-voltage breakdown values obtained on oil-treated paper-insulated cables over the insulation thickness range from 0.187 inch to 0.600 inch. The average stress at breakdown approximates 1,600–1,700 volts per mil. High-density papers show some superiority over ordinary-density papers. Cathode-ray oscillograms of the testing wave ($1^1/_2$x40 impulse wave—positive polarity) before and at breakdown are included for a typical test.

INFORMATION on the impulse strength of high-voltage apparatus has accumulated steadily in the last 20 years due particularly to advances in technique of generation and measurement of high-voltage surges. Line insulators, bushings, transformers, and other apparatus have been tested. Cables have received attention during the last decade of this period, and the literature is beginning to record this information.[1,2]

This paper presents data on the impulse breakdown voltage of oil-treated paper-insulated cables over the range of insulation thickness from 0.187 inch (0.472 centimeter) to 0.600 inch (1.520 centimeters). The impulse breakdown voltage at the latter thickness was of the order of 1,000,000 volts. Cable breakdown tests are necessarily destructive of the sample and involve many samples and a costly preparation procedure. Data thus accumulate more slowly than in cases involving air flashover. These data have been accumulated over the period 1931 to 1938. The testing technique has differed somewhat during this period; early tests employed a 1x10 wave (that is, one microsecond to crest voltage, ten microseconds to decrease to one-half crest voltage); later tests employed a $1^1/_2$x40 wave. In all cases a positive impulse was applied to the cable conductor, the lead sheath being connected to ground.

The tests on the thinner (0.187 inch) insulation were made on samples having ten feet of lead. The ends were built up with a varnish-cloth reinforcement over which was placed a spun-copper stress-distributing bell. This latter was connected to the sheath by a closely wrapped spiral copper braid on the lower slope of the varnished-cloth reinforcement. The whole cable was then immersed in an oil-filled tank. All other tests were made on 16-foot (lead length) samples using standard porcelain oil-filled terminals of usual design. All cable failures secured were in the leaded portion of the cable.

Paper 40-8, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE winter convention, New York, N. Y., January 22–26, 1940. Manuscript submitted November 14, 1939; made available for preprinting December 6, 1939; released for final publication February 29, 1940.

C. M. Foust and J. A. Scott are in the general engineering laboratory, General Electric Company, Schenectady, N. Y.

Acknowledgment is made for the many details of testing, preparation of cable samples, and for the specialized impulse-testing technique to J. B. Felter, C. Zubal, and N. Rohats.

1. For all numbered references, see list at end of paper.

Impulse Generator

The impulse generator used for these tests has a 2,000-kv open-circuit rating and is of the parallel-charging, series-discharging type. The d-c charging voltage is 200 kv for each of the ten parallel capacitor banks. The generator has a series capacitance of 0.0067 microfarad and a circuit inductance of 75 microhenries.

The circuit arrangement used is shown in figure 1. The wave-front time is determined by the resistance-capacitance combination R_1C_2 and the wave tail by the resistance R_2 and the combined capacitances C_1 and C_2. The determination of these values is done experimentally and without delay on the oscillograph electric-transient analyzer.[3,5] All oscillograph records were taken with the type *HC*-15[4,5] hot-cathode high-vacuum high-voltage cathode-ray oscillograph.

Table I. Specimen Sphere Gap–Cathode-Ray Oscillograph Calibration Check

Surge-Generator No.	Excitation, Volts	Sphere Gap (100 Cm) Setting (Cm)	Voltage (Kv)	Corrected Kv	Cathode-Ray Oscillograph Milli-meters	Volts	Ratio	Kv	Deviation (Per Cent)
10	40	3.59	100	105	22.2	913	113	103	−1.3
11	40	3.59	100	105	22.2	913	113	103	−1.3
12	40	3.59	100	105	15.5	637	162	103	−1.6
13	40	3.59	100	105	15.5	637	162	103	−1.6
14	78	7.62	200	210	31.0	1,274	162	207	−1.5
15	78	7.62	200	210	30.8	1,266	162	206	−2.1
16	78	7.62	200	210	21.8	897	228	204	−2.8
17	78	7.62	200	210	22.1	909	228	207	−1.5
18	119	12.53	300	315	34.5	1,418	228	323	+2.4
19	119	12.53	300	315	34.2	1,406	228	320	+1.6
20	119	12.53	300	315	24.5	1,007	328	330	+4.6
21	119	12.53	300	315	23.2	995	328	326	+3.3

Pressure, 77.37 centimeters mercury; temperature, 14 degrees centigrade; relative air density, 1.056; gap correction, 1.052.

Demonstration of Measurement Accuracy

Standard procedure used in these tests for calibration of the surge generator is given in the recently revised AIEE Standard No. 4, "Measurement of Test Voltage in Dielectric Tests". This calibration recommends an intercomparison between sphere gap and cathode-ray oscillograph for demonstration of measurement accuracy. These intercomparisons were made at frequent times during this cable-testing program. Record of one such comparison is reproduced in table I. The deviation between sphere gap and oscillograph

sive weight in the distribution lines. This seems to eliminate the 24-volt d-c system when a large number of motors is used. At 110 volts, the 400-cycle three-phase a-c system offers some attractive weight-economy possibilities because of high-speed induction motors. In considering auxiliary-power-plant efficiency on airplanes it is obvious that "weight efficiency" is the determining factor. In the analysis of an auxiliary power system there is no question about its importance. "Weight efficiency" requires consideration of the fuel, oil, engines, generators, control, distribution system, motors, lights, radio, and any other loads. The efficiency of a specific part of the system must be selected to attain the lowest total weight.

Table II.

Specimen Breakdown Test on High-Voltage Cable

Thickness 315 Mils, $1^1/_2 \times 40$ Wave

Number	Surge Generator (Volts)	Cathode-Ray Oscillograph: Deflection Mm	Deflection Volts	Divider Ratio	Kv	Time to Breakdown (μ Sec)
1	56.0	10.4	427	773	329	
2	60.5	11.4	468	773	362	
3	64.5	12.3	506	773	391	
4	68.0	13.0	537	773	415	
5	72.0	14.0	576	773	445	
6	75.0	14.7	605	773	467	
7	78.0	15.5	635	773	490	2.6

Time-Scale Calibration

Number	Frequency (Cycles Per Sec)	Time Scale (μ Sec)
8	500,000	5.9 average

Deflection Calibration

Number	Applied Voltage	Deflection Mm	Deflection Volts Per Mm
9	250	6.3	39.6
	500	12.0	42.5
	750	18.3	41.1
			41.1 average

Table III. Impulse Breakdown Values for 33 Cables Having Oil-Treated Paper Insulation Ranging From 0.187 Inch to 0.600 Inch Thick, Tested at 25 to 30 Degrees Centigrade

Cable Number	Conductor Size (Stranded)	Thickness of Insulation (Inches)	Paper Density	Oil Viscosity at 100 Deg F (Saybolt Sec)	Impulse Breakdown (Kv Crest)‡
1	00 Brown and Sharpe*	0.187	0.8	2,500	350
2					350
3					350
4					350
5					350
6					375
7					400
8	2,100,000 circular mils**	0.315	1.0–1.1	100	610
9					512
10		0.315	0.8	100	448
11					453
12					461
13		0.315	40 per cent 1.0–1.1, 60 per cent 0.8†	100	500
14					490
15		0.315	Medium density	100	555
16					559
17					559
18		0.500	1.0–1.1	100	730
19					765
20		0.500	0.8	100	630
21					648
22		0.500	40 per cent 1.0–1.1, 60 per cent 0.8†	100	902
23					928
24					940
25	500,000 circular mils‖	0.600	40 per cent medium, 60 per cent 0.8†	100	1,067
26					1,104
27					1,115
28					856
29					916
30					836
31		0.600	Medium density	100	896
32					940
33					1,014

* Stranded; 0.420 inch outside diameter. Solid-type cable.
** Hollow core; 1.890 inch outside diameter. Oil-filled cable.
‖ Hollow core; 1.03 inch outside diameter. Oil-filled cable.
† Graded insulation with higher-density paper next to the conductor.
‡ Wave shape of first seven tests was 1x10, of all others $1^1/_2 \times 40$ as defined by (microseconds to crest) − (microseconds to half value).

is below five per cent for this record and for all comparisons made during these tests, satisfactory accuracy for such measurements.

Testing Procedure and Calibrations

The routine followed in applying the impulses was as follows. The generator having been adjusted to give the desired

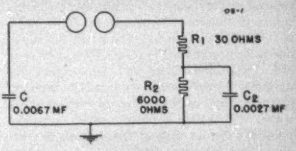

Figure 1. Impulse-generator circuit schematic diagram

Constants shown are for the cables of group C of figure 3

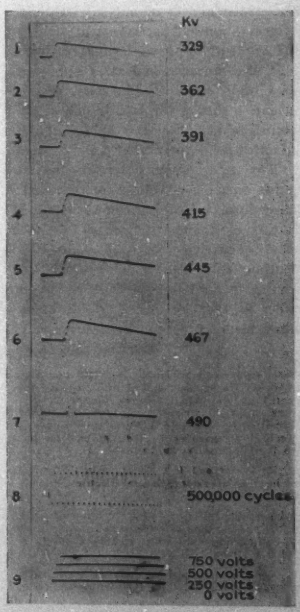

Figure 2. Specimen oscillograph record of impulse-breakdown test on cable sample with calibrating records

1–6—Successively applied impulse-voltage waves of increasing crest value
7—Impulse wave producing cable failure
8—Oscillator wave for time-axis calibration
9—Direct-voltage records for deflection calibration

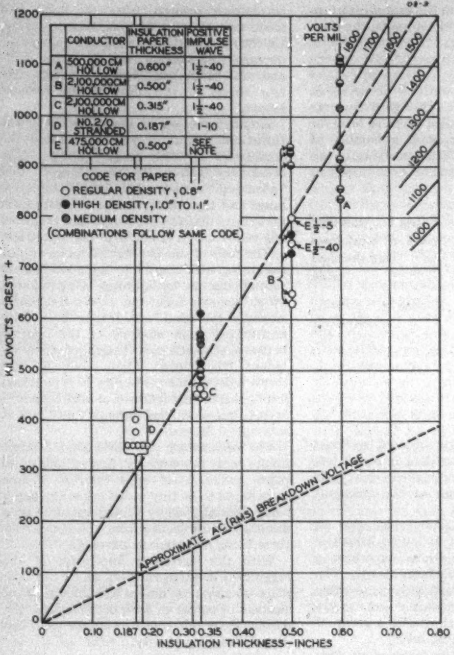

Figure 3. Summary of impulse tests on cable insulation

wave shape and its excitation calibrated in terms of crest kilovolts, an impulse was applied to the cable of a magnitude well below (approximately 50 per cent) expected breakdown. Successive single waves were then applied, each exceeding the previous wave by an approximately constant increment until a cable-insulation breakdown was obtained. Failure was indicated in the tests made in 1931 by the action of a surge-crest ammeter[4] inserted in the ground lead from the cable sheath; in all tests made since that time a cathode-ray oscillograph[5] was employed using a resistance voltage divider, and an oscillogram was obtained of each wave up to and including the one causing failure. The magnitude of the crest voltage was obtained from the cathode-ray oscillograph deflection and voltage-divider ratio as indicated in table I. Practically all failures occurred on or near the crest of the wave.

Specimen Record

A specimen oscillograph record is reproduced in figure 2 wherein are recorded the six full ($1^1/_2$x40) waves at increasing voltage amplitudes followed by the wave at 490 kilovolts crest which caused cable failure. The eighth record is that of a 500,000-cycle timing wave and the ninth a deflection calibration. The data pertaining to all these are given in table II. The recorded waves were analyzed to be 1.55 microseconds to crest and 39.3 microseconds to half value on the wave tail.

Results

Figure 3 shows the results obtained in these tests. Plotted here is kilovolts crest against insulation thickness. Table III records the numerical values. No attempt has been made to draw a curve through the points. In fact, the dispersion is such that a straight line fits the data as well as does a curve. A polar-co-ordinate system has been superimposed from which the average stresses (volts per mil) may be read. An average figure of 1,600 volts per mil may be carried in mind as representative.

It is not attempted to take account of the stress variation between conductor and sheath, although conductors from number 2 Brown and Sharpe to 2,100,000-circular-mil hollow with outside diameters of 0.420 inch and 1.890 inch respectively were used. The tests included several grades or densities of papers, and in general the denser papers gave higher breakdown values. In the presence of the natural variation or dispersion of the results, including the fact that many samples included graded insulations, an accurate statement cannot be made comparing the different densities. We may perhaps infer that the dense papers yield results 10–15 per cent better than the lower-density papers.

The results reported in this paper are in excellent agreement with those reported by Held and Leichsenring,[2] who tested over nearly the same range of insulation thickness.

All the tests here reported were made with positive polarity and with waves of 1 to $1^1/_2$ microseconds wave front. However, as far as analysis of breakdown values reported herein are concerned, the wave-shape change is not important. The wave fronts were practically the same, and failures occurred most frequently on or near the wave crest. A 1x10 wave was used on the earlier tests as a compromise between the 1x5 and $1^1/_2$x40 waves then most common. Later, as the 1x5 wave diminished in use, all tests were made with the $1^1/_2$x40 wave. These waves are those in most common use in this country for impulse testing.

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Discussion

Herman Halperin: See discussion, page 399.

P. L. Bellaschi and W. L. Teague: See discussion, page 400.

L. G. Smith: See discussion, page 401.

J. H. Hagenguth (General Electric Company, Pittsfield, Mass.): Several years ago tests were made in the high-voltage engineer-

ing laboratory in Pittsfield to determine the volt-time characteristic of a cable. Although in general high-voltage cables probably are not subjected to steep-fronted lightning waves, it might be of interest to publish the result.

The cable sections tested were prepared similarly to the samples described in the paper with the exception that the leaded portion was only ten inches long as compared to ten feet in the paper. The total length of a sample was 4½ feet. The whole section was immersed in oil. All failures occurred in the leaded section.

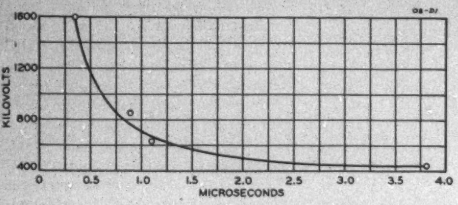

Figure 1. Volt-time curve of breakdown on lead-sheathed cable

Negative polarity, 1.5x40 wave

The cable had a conductor of 500,000 circular mils, 0.281-inch paper insulation, oil treated, and a total outside diameter of 1.6 inches. Tests were made with negative polarity.

For determining the minimum breakdown strength, tests were started at a voltage of approximately 60 per cent of the expected failure voltage. Voltage was raised in about 25-kv steps until failure occurred at 440 kv. Two impulses were applied at each step.

The breakdown voltage thus obtained is probably somewhat too high for design purposes, because it does not take into account the effect of successive strokes on the breakdown. In transformer insulation the damaging corona level is reduced to 80 per cent of the single-shot corona level, when 15 or more impulses are applied. In a cable with its more uniform field and uniform insulation, the multishot breakdown probably is not quite as much lower as in transformer insulation but nevertheless their effect must be taken into account to arrive at the proper safety factors.

The other three sections were tested by applying various amounts of overvoltage to the cable and recording the resulting failure by means of a cathode-ray oscillograph. For the purposes of the investigation described, the few breakdown points obtained showed results which gave a sufficiently consistent curve as shown in figure 1 of this discussion. However, a greater number of points and different thicknesses of insulation would have to be investigated for design data.

Of interest is a comparison of the overvoltage characteristics of various electrode shapes in comparison with the cable. This is shown on figure 2 of this discussion for a 20-inch rod gap, a 10-centimeter sphere gap at 20 centimeters spacing and the cable.

It is interesting to note that the cable in spite of the relatively uniform field has a much steeper characteristic than the sphere and even approaches the characteristic spark-over curve of the 20-inch gap at 0.5 microsecond. The reason for this behavior may be imperfections in the lead sheath producing point effects and corona on the positive sheath.

R. W. Atkinson (General Cable Corporation, Perth Amboy, N. J.): In regard to surge strength of paper in cable we have been for some time depending upon a number of tests made in 1931. It is gratifying to observe the close agreement between these and the more complete series reported by Foust and Scott. Besides our data in direct line with Scott's we are reporting here some tests tending to answer some of the questions which have been asked.

Our tests were made on cables with an insulation thickness of 190 mils, which is identical with the thickness on which a number of tests were made by Scott. The average value of 12 tests directly comparable with his was 348 kv, which is almost exactly the same as the value shown for a group of his tests on corresponding cable.

The tests included in the above group were all made with surges of positive polarity. A few tests were with surges of negative polarity. These required slightly higher voltage to produce breakdown than required for breakdown of similar cable tested with positive polarity.

Half of the samples were made with paper of high density and half of lower density. The average strength of those with high-density paper was 18 per cent greater than for those of low density. It is noted that this is somewhat greater than found by Scott but reasonably comparable with his figures.

Two longer lengths were subjected to 83 and 115 repeated surges respectively. In the first surges, the applied surge voltage was about 60 per cent of the expected surge breakdown. Ten shots were applied after which the applied voltage was increased by about 6 per cent of the expected breakdown. A third set of ten shots at 6 per cent higher voltage was then applied, after which successive sets of ten shots each were applied with voltage increments of 3 per cent until failure occurred.

While the voltage of the ten successive shots at one setting was substantially the same, this repetition would not be exact. Thus the fact of failure at other than the first shot at one voltage may be due either to the cumulative effect of successive shots at substantially the final breakdown value or may be due to a slightly greater voltage at the surge producing failure than on the preceding surges at the same nominal voltage.

On one of the lengths, 35 of the shots were at a value within 10 per cent of the average surge breakdown of similar cable and the breakdown occurred after the cable had stood two surges at the breakdown setting. On the other, 33 of the shots were above the average surge breakdown of similar cable and the surge breakdown occurred after four surges at the same setting without failure.

Another portion of the same cable was tested similarly at 60 cycles but without the application of the surge voltage. The breakdown voltage on the "surged" and "unsurged" samples fell within the same range and thus there was no evidence from these tests that the 100 surges had produced any reduction in strength of the insulation.

The tests of this last named series appear reassuring with respect to the possibility of partial puncture by lightning being followed by subsequent failure at power frequency. Actually the result could have been fully anticipated from analysis of the relation between strength and length of time required for failure. These tests do not throw light on the possibility of a puncture from lightning not followed at once by power failure, but producing damage that leads to subsequent failure.

The appearance on dissection of surge failure not followed by power failure in paper cables, is of some interest. These were found to be tiny radial holes, the paper being "burred," as by being punctured by a minute fast projectile from the conductor, there being no apparent burning.

With the increasing knowledge of the magnitude of surge voltages which can take place on a system, and of the amount of resistance of cables to such disturbances, the danger from this cause of failure has been diminished very greatly.

L. I. Komives (nonmember; The Detroit Edison Company, Detroit, Mich.): First of all the authors of this paper are to be congratulated for the valuable data which they collected in a field largely unexplored.

1. I am rather puzzled with the results presented in this paper because the voltage

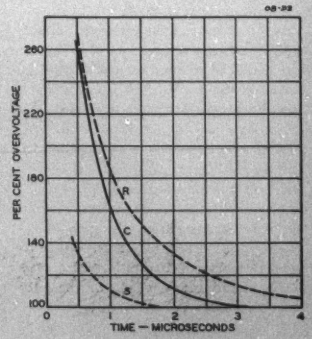

Figure 2. Negative-voltage characteristics

C—Cable, 0.281-inch oil-treated paper (440 kv critical)

R—Rod gap (410 kv critical)

S—Sphere gap (450 kv critical)

100 per cent equals critical breakdown voltage

gradient seems to have had no effect whatsoever on the impulse strength of the cables tested by the authors. In our rather incomplete experiments we found that the voltage gradient has a very strong influence on the impulse strength.

2. We have also found that uniformity of the taping has a very decided influence on the impulse strength. No mention whatsoever was made in the paper in this respect.

3. I feel that the results shown on small-size copper conductors (samples 1 to 7—table III) are due to a highly viscous oil used in these cables in contrast with the much lower viscosity oils of the rest of the samples. I would like to know whether the authors concur with this explanation.

4. We feel that it is perhaps of more importance to cable users to know just what the impulse strength of a piece of cable is when tested with the maximum potential available. Although the general opinion is that potentials lower than those causing breakdown of the insulation have practically no effect on the insulation because of the short time involved, we have reasons to believe that every application weakens the insulation and therefore, testing cables with consecutively high potentials does not indicate the true impulse strength of the insulation.

5. I would like to know what the "medium density" paper mentioned in table III of the paper is.

Wm. A. Del Mar (Phelps Dodge Copper Products Corporation, Yonkers, N. Y.): The following questions occurred to me in reading the paper:

1. Would any materially different values of volts per mil have been obtained if actual rather than nominal insulation thicknesses had been used?

2. Were any of the cables shielded with copper shielding tapes? Would the use of such tapes, by holding the paper tapes firmly together, increase the impulse strength?

3. With unexplained variation of impulse strength from 1,300 to 1,900 volts per mil on one wall thickness, is it safe to base insulation walls on impulse strengths higher than 1,300 volts per mil?

4. Figure 1 shows a resistor R_1. Is there any reason for preferring this to a reactor?

C. M. Foust and J. A. Scott: In J. H. Hagenguth's discussion he has added three front-of-wave short-time breakdown values and a minimum breakdown value on 0.281-inch paper to our test data. The minimum breakdown value is a good check on our values for this thickness, being almost exactly on our average curve. The three short-time values permit an approximation of the volt-time curve from actual test data on cable samples down to 0.4 microsecond. The comparison of rod gap, cable, and sphere gap volt-time curves wherein the cable curve conforms more nearly to the 20-inch rod-gap curve than to the spheres suggests a long breakdown path, possibly in many parts parallel to and between paper layers.

The authors appreciate the discussion contributed by Messrs. Bellaschi and Teague, pertaining to volt-time breakdown relations for short time periods. Other than that the point of breakdown on the wave shape was recorded by cathode-ray oscillograph, no effort was made in our work to gather data on volt-time relations. As pointed out in the paper, all failures occurred at the crest or a short time after, indicating very little increase in voltage down to 1.5 microseconds for wave-crest failures. This, the authors presume, is the basis for the statement by Messrs. Bellaschi and Teague that the volt-time characteristic is essentially constant down to one or two microseconds. However, Mr. Hagenguth's data which was taken on the wave front indicates a 20-per cent increase in voltage at 1.5 microseconds. This is likely due to the fact of the wave-front failures being higher than wave-crest values at the same time point.

In commenting on L. G. Smith's discussion, he is correct in presuming that the values are for new cable. We agree that similar data on cable having been in service for some time are desirable. It seems logical to expect that there should be no change in impulse strength with age for oil-filled cable, while solid-type cable might show a decrease due to void formation. The point of variation of breakdown strength with conductor size has been twice referred to in the discussion with the inference that our tests showed no such variation. We did not wish to convey this impression. To determine such a relation accurately would require a large number of tests with different sizes of conductors and a range of insulation thicknesses for each. Such a test program on high-voltage cable samples is quite formidable. We wish to say that because of the dispersion of our test points analysis of the data did not provide us with a sufficiently definite relation between conductor size and breakdown to warrant comment.

Mr. Atkinson has referred to a considerable group of data taken by his company. He had very kindly made these results available to us early in our investigation. To show the good agreement between these results as well as those reported by Held and Leichsenring (reference 2 of the paper), figure 3 of this discussion consolidates these together with some other data identified in the figure. It is here seen that all data from some six sources are in excellent agreement. An excellent idea of the spread of the values is given. This spread is very reasonable for such breakdown values.

Mr. Atkinson also refers to the lack of damage done by impulses of value somewhat below the breakdown value. This freedom from so-called "impulse fatigue" is verified in our own experience. For example, in our tests on the samples having 0.187-inch paper, two additional samples were subjected, one to 100 impulses at 325 kv, the other to 500 impulses at 300 kv; following this single impulses at 25-kv increments were applied. Both cables failed at 375 kv which compares with the highest results obtained on samples 1 to 7 reported in the paper. However, an open mind should be kept on this subject, as indeed on all aspects of this relatively young subject, for we have seen unpublished data from abroad where on relatively thin samples several thousand successive shots did produce a decrease in the breakdown value.

In reply to Mr. Komives in the order of his questions:

1. We would agree that voltage gradient is probably the controlling factor in the breakdown

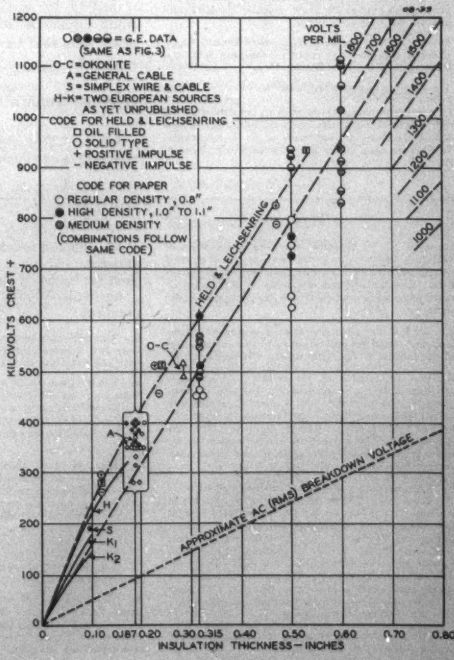

Figure 3. Summary of impulse tests on cable insulation

Impulse Strength of Cable Insulation

E. W. DAVIS
FELLOW AIEE

W. N. EDDY
FELLOW AIEE

INSULATED CABLES often are exposed to lightning and often have been damaged by lightning, especially rubber- or cambric-insulated cables of medium or lower voltage. It is also true that some service trouble has been improperly attributed to lightning. Knowledge of the impulse strength of cable insulation is necessary to analyze such cases correctly and to minimize lightning trouble by proper cable design. In spite of the practical need for such information there seems to be a conspicuous lack of it in the literature.

From time to time for several years we have been making impulse tests on cable insulation, either as we needed the data or as we got the opportunity. As a result we have accumulated a general assortment of data without conducting a complete or continuous investigation. We have found these data worth while and hope eventually to make the data complete enough to merit a more detailed analysis than seems justifiable at present. In the meantime we are reporting the results to date with the hope that the ensuing discussion will uncover results of other tests that have been made but not reported.

Paper 40-34, recommended by the AIEE committee on power transmission and distribution, and presented at the AIEE winter convention, New York, N. Y., January 22–26, 1940. Manuscript submitted November 29, 1939; made available for preprinting December 21, 1939; released for final publication February 29, 1939.

E. W. Davis is chief electrical engineer and W. N. Eddy is experimental engineer, Simplex Wire and Cable Company, Cambridge, Mass.

The data in the paper represent the efforts of several people at irregular intervals over the last four years. In particular the authors wish to acknowledge the valuable advice of C. M. Foust in building generator 2 and the conscientious work of S. N. Alexander, W. D. Fenn, and Oscar Hess in calculating and testing.

Impulse Generators

Each testing impulse consists of a nonoscillatory increase and decrease of voltage at a definite rate. Two different impulses have been used for these tests, a 1x10 wave and a 1.5x40 wave. The first figure in each designation is the time in microseconds from the beginning of the impulse to the crest of the impulse. The second figure is the time in microseconds from the beginning to the point on the impulse tail at which the voltage has fallen to one-half the crest or maximum value.

The impulses are generated by discharging a capacitance through a resistance. The resulting voltage drop across the resistance is the impulse. The shape of the impulse is controlled by the values of the constants in the discharge circuit; the impulse front by inductance in series or capacitance in parallel with the resistance and the impulse tail by the resistance itself. The assembly necessary to produce these impulses constitutes the impulse generator.

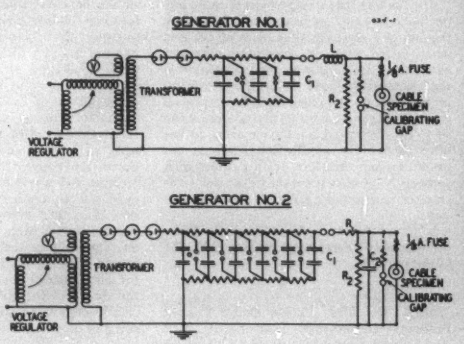

Figure 1. Connections

Figure 1 shows the connections of the two generators that were used for the tests. In both, the necessary high discharge voltage is attained by the familiar Marx circuit which has been fully described in the literature. The differences between the two generators are evident from the connections in figure 1 and the ratings and circuit constants in table I.

Generator 1 was made several years ago, using available glass plates for the main capacitance. The constants in the discharge circuit were adjusted for a 1x10-microsecond wave because this was the intermediate of the three waves then in common use for testing lightning arresters.

Generator 2 was built more recently, in order to enlarge the range of sample length and size that could be tested. The discharge circuit was adjusted to a 1.5x40-microsecond wave because this

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strength. It is, however, only one of a number of variables and we chose the more practical minded way of plotting breakdown against insulation thickness. Conductor sizes are given so that approximate maximum gradients may be calculated if desired.

2. We felt that the uniformity of taping was excellent and found no indication from the examination of the failures to indicate taping to be at fault.

3. We see nothing in our results to lead us to attribute different performance to the two different viscosities of oil used. As a first approximation we would assume them to be identical. Samples 1 to 7 of table III have thinner insulation than the remainder and consequently benefit somewhat by any curvature that may exist in the breakdown voltage-thickness curve.

4. The alternative method of testing referred to by Mr. Komives is highly interesting. We proceeded the way we did because we were on untried ground and we preferred to feel our way along as it were. Our results we feel are more indicative of the lowest breakdowns that might be obtained and consequently more useful in estimating safely sustained voltage values. However, the procedure suggested has its merits and will, we hope, be used. We have already referred to "impulse fatigue" in connection with Mr. Atkinson's discussion.

5. The medium-density paper was a special paper having a density of 0.85 or lower.

Mr. Halperin emphasizes nicely a number of points and gives some valuable suggestions for further work.

Answering Mr. Del Mar in the order of his questions:

1. The difference between actual insulation thickness and nominal thickness was small compared with the variation in breakdown-voltage results.

2. No shielding tapes were used. Since all tests were made on single-conductor cables, which were newly manufactured and whose sheaths had not been expanded by heating and cooling cycles, our results should be the same as if shielding tapes were used.

3. Mr. Del Mar's third question covers a lot of ground. To answer it briefly our consolidated data between 0.315-inch thickness and 0.600-inch thickness regardless of the particular construction of the cables (paper, etc.), indicates the probability that five per cent of such a group of cables would fail at 1,300 volts per mil or less. (Average breakdown, 2d tests = 1,615 volts per mil; $\sigma = 191$ volts per mil or 11.8 per cent of average.) Such variation is typical of breakdown data.

4. Other circuits, of course, than that shown in figure 1 may be used. We preferred a resistor, R_1, to a reactor because of the lesser liability to oscillations which frequently occur when lumped reactors and capacitors are used.

shape had become generally accepted as the standard test wave. The ballast capacitance in parallel with the sample has two functions; to help control the wave shape and to decrease the effect of changing sample capacitance on the wave shape.

Our principal purpose in making these tests was to compare different sizes and types of cable on an impulse reasonably representative of lightning, without attempting to get co-ordination with other impulse data in the literature. Therefore, we have been more interested in keeping our wave shape constant or fixed than in making sure it was exactly 1x10 or 1.5x40. For this reason we have not yet considered it necessary to acquire a cathode-ray oscillograph and our wave shapes therefore have not been confirmed by oscillograph. The test results in table II indicate that the value of our results is not seriously reduced by this omission.

Each test is made by increasing the charging voltage in seven-kv steps usually beginning at 50 per cent of the estimated breakdown voltage. Each voltage is held constant while two successive impulses are applied to the sample by lowering a third sphere into the first-stage gap. Failure of the sample is indicated by explosion of the one-eighth-ampere fuse wire in series with the sample. The test voltage is indicated by a voltmeter coil in the charging transformer calibrated in terms of a sphere gap in parallel with the test sample. Both ends of the sample are connected together. Various arrangements of the sample were tried without finding any effect on the impulse strength.

Figure 2 shows the general arrangement of generator 2. At the left is the portable control table connected to the generator through two multiconductor portable cables. The voltage regulator controls the input to the transformer in the corner which through the tube rectifiers charges the capacitors on the wooden rack. The stage resistors consist of water in the garden hose visible along the upper edge of the rack. The third or trigger sphere is visible just above the first stage gap. A sample of plain rubber wire is shown ready for test in water. The series fuse wire is on the framework above the water drum. The motor on the floor is circulating a sodium carbonate solution through the vertical hose for R_1 and R_2. The capacitor bank at the right is the ballast capacitance or C_2.

Table I. Ratings of Impulse Generators

	Generator 1	Generator 2
Maximum discharge voltage at terminals of C_1 (kv)	300	600
Maximum voltage on specimen (kv)	260	550
Main capacitance C_1		
(μf per 50 kv)	0.04	0.5
(μf at full voltage)	0.0067	0.042
Ballast capacitance C_2 (μf)	None	0.0048
Discharge resistance R_1 (ohms)	None	115
R_2 (ohms)	2,300	1,100
Calculated wave shape	1x10	1.5x40

Table II. Effect of Wave Shape on Impulse Strength (Volts Per Mil)

	Generator 1—1x10 Wave			Generator 2—1.5x40 Wave		
	Average	Maximum	Minimum	Average	Maximum	Minimum
Cambric	1,050	1,120	1,000	1,090	1,150	1,050
Rubber	1,080	1,300	900	1,070	1,240	915

Table III. Effect of Impulse Polarity on Impulse Strength of Rubber-Insulated Wire

Wire Size	Insulation Wall	Impulse Polarity	Impulse Strength in Volts Per Mil: Average	Maximum	Minimum	Ratio, Positive/Negative (Average)
No. 6 solid	8/32-inch	Positive	1,033	1,150	900	0.84
		Negative	1,225	1,300	1,200	
No. 6 solid	16/32-inch	Positive	1,400	1,550	1,250	1.09
		Negative	1,290	1,450	1,150	
No. 6 solid	24/32-inch	Positive	928	1,050	780	1.02
		Negative	905	1,000	850	

Effect of Wave Shape on Impulse Strength

These tests were made on five-foot adjacent samples taken from two lengths of single-conductor cable, number 6 solid, 8/32-inch wall of insulation, lead sheath, one length insulated with rubber and one with varnished cambric. In table II are the results in volts per mil wall, the average, maximum, and minimum of five tests. Samples from both lengths were tested with each of two different impulse wave shapes, 1x10 and 1.5x40.

The results show no definite difference in strength between the two wave shapes in spite of the considerable difference in shape. One wave is 50 per cent slower than the other on the front and four times longer than the other on the tail. This lack of a real difference in strength between the two waves is good evidence that a reasonable deviation in our wave shape from the calculated should have no appreciable influence on the test results, and therefore that the lack of an oscillograph should not seriously limit the value of the test results.

This lack of difference also indicates that any conclusion based on either shape should hold for the other shape and for a fairly large range of impulses occurring in actual service.

Effect of Impulse Polarity on Impulse Strength

Table III shows the effect of impulse polarity on the impulse strength of three

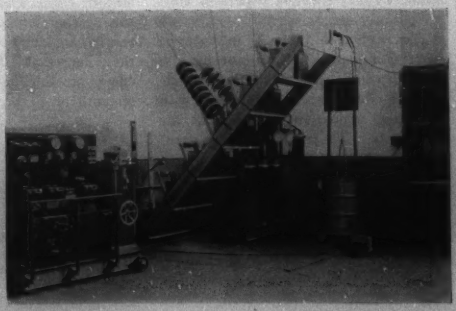

Figure 2. Generator 2

Table IV. Effect of Electrode Surface on Impulse Strength (Volts Per Mil)

	Average	Maximum	Minimum
Lead sheath	1,400	1,490	1,300
Rubber surface in 0.1 per cent salt water	1,390	1,440	1,300
Lead foil wrapped around rubber insulation	1,410	1,480	1,340

different sizes of rubber-insulated wire. The tests were made on five-foot samples with generator 1 and the 1x10 wave.

On the average no real difference in strength is indicated between the two polarities. Unless specified otherwise all other tests reported in this paper were made with the negative polarity.

Impulse Strength of Rubber-Insulated Wire—Effect of Electrode Surface

Table IV gives the results of tests made on five-foot samples of number 6 solid, $^6/_{64}$-inch wall of rubber, using three different kinds of outer electrode surface. All tests were made on generator 2 with the 1.5x40 wave. The results are in volts per mil wall, average, maximum, and minimum of at least five tests.

These results show that any one of these types of outer electrode can be used indiscriminately. In most cases the salt water is most convenient for testing rubber-insulated wire.

Impulse Strength of Rubber-Insulated Wire—Effect of Specimen Length

All samples used for these tests were taken from the same length of wire, single conductor number 6 solid, $^6/_{64}$-inch wall of 60 per cent high-voltage rubber compound, tape, and lead sheath. Generator 2 was used with the 1.5x40 wave. Table V gives the test results in volts per mil of wall.

The results in table V indicate no effect of sample length on the impulse strength of the wire, while the 60-cycle strength of the same wire decreases with increasing sample length at about the usual rate. We have seen this unexpected tendency of the impulse strength in other of our test results but plan to investigate it further before accepting it as conclusive. There has been no tendency for the faults in the longer samples to be located near the sample ends. Different arrangements of the longer samples have been tried without finding any consistent effect. Without a cathode-ray oscillograph we have been unable to determine the effect of the sample capacitance on the wave shape, but in view of the results in table II we doubt that this effect is sufficient to affect the impulse strength.

The ratios of impulse to 60-cycle strength in table V are seen to be considerably lower than those in table VII because the rather high 60-cycle strength of the table V wire is not accompanied by abnormally high impulse strength. That is, the impulse strength does not seem to have any fixed relation with the 60-cycle strength. On five-foot samples the ratio may vary from two to four.

Impulse Strength of Rubber-Insulated Wire—Effect of Insulation Thickness

These tests were made on five-foot samples of rubber-insulated wire in salt water, using generator 1 with the 1x10 wave. Five samples were tested at each of seven different wall thicknesses between $^5/_{64}$ and $^{23}/_{64}$ inches, on a number 6 conductor or thereabouts. All insulating walls were 60 per cent rubber but of slightly different types. For this reason the actual results gave a rather irregular plot versus wall thickness. The results given in table VI represent a smooth curve averaging the actual results. Therefore, although the reported results are subject to some variation, they represent the trend or general effect of thickness on the impulse strength of 60 per cent rubber insulation on a number 6 conductor.

In table VI these average results of unit impulse strength decrease with increasing wall thickness. The same tendency has been shown by the a-c strength of many insulations.

Impulse Strength of Rubber-Insulated Wire—Effect of Compound Type

It is well known that there are many different types of rubber cable insulation and that they may differ considerably in their properties. Each type is designed and used for a particular kind of service. The results of table VII are given to show the effect of the rubber compound type on the impulse strength and the ratio between that strength and the 60-cycle dielectric strength.

All samples were five-foot active, number 6 or number 8 with $^5/_{64}$-inch or $^6/_{64}$-inch wall, tested in salt water on generator 2 with the 1.5x40 wave. The results are in volts per mil wall.

The results in table VII indicate at least general correlation between the impulse and 60-cycle strengths. Because of variables in each type of compound that are outside of the present discussion, the impulse and 60-cycle strengths of each type are subject to some variation from the values given. But the results in table VII serve to give the general magnitude and to indicate that the impulse strength of rubber compounds may be as high as 1,600 volts per mil and as low as 700 volts per mil for these insulation walls. In general the impulse strength is seen to be about three times the 60-cycle strength.

Impulse Strength of Rubber-Insulated Tree Wire

These tests were made on generator 2 with the 1.5x40 wave, using five-foot samples of number 6 solid, $^5/_{64}$-inch wall of rubber, braid, with and without fiber

Table V. Impulse Strength of Rubber-Insulated Wire—Effect of Specimen Length

Specimen Length (Feet)	Specimen Capacitance (μf)	Impulse Strength (Volts Per Mil) Average	Maximum	Minimum	60-Cycle Strength (Volts Per Mil)* Average	Maximum	Minimum	Ratio, Impulse to 60 Cycle (Average)
1	0.00006	1,050	1,230	900	580	690	510	1.8
2	0.00012	1,120	1,260	960	550	590	500	2.0
5	0.0003	1,117	1,240	920	496	550	420	2.2
10	0.0006	1,231	1,380	1,020	470	520	430	2.6
20	0.0012	1,130	1,340	920	440	490	400	2.7
40	0.0024	1,128	1,330	925	415	510	380	2.7

* All 60-cycle strengths given in this or other tables are effective and not peak.

Table VI. Effect of Wall Thickness on Impulse Strength of Rubber-Insulated Wire

Insulation Wall in 64ths Inch	Impulse Strength in Volts Per Mil
5	1,400
10	1,150
15	970
20	800

tape under the braid, dry and after soaking in water for 20 hours. The dry tests were made with lead foil wrapped over the wire and those after soaking were made in water. Each result given in table VIII is the average of at least five tests on adjacent samples. The 60-cycle tests were made by increasing the voltage three kv per 15 seconds.

The impulse strength of this type of wire is particularly important because the wire is directly exposed to lightning and the insulation wall is seldom more than $^3/_{64}$ inch. In table VIII the impulse strength is seen to be generally typical for that rubber wall. The differences between the two types of wire are not enough to indicate that the fiber tape is of any real value as insulation, especially when the wire is wet.

Table IX. Impulse Strength of Cable—Rubber Versus Cambric Versus Paper

Insulation	Impulse Strength (Volts Per Mil)			60-Cycle Strength (Volts Per Mil)			Ratio, Impulse to 60 Cycle (Average)
	Average	Maximum	Minimum	Average	Maximum	Minimum	
Anhydrex rubber	1,143	1,300	900	350	400	310	3.3
Cambric	1,040	1,100	1,000	300	360	250	3.5
Paper	1,920	2,000	1,770	540	570	520	3.6

Table X. Impulse Strength of Sheets—Rubber Versus Cambric Versus Paper

Insulation	Impulse Strength (Volts Per Mil)			60-Cycle Strength (Volts Per Mil)			Ratio, Impulse to 60 Cycle (Average)
	Average	Maximum	Minimum	Average	Maximum	Minimum	
Paper—two layers	3,890	4,400	3,550	1,600*	1,900	1,480	2.4
Cambric—two layers	3,630	4,000	3,200	1,400*	1,590	1,220	2.6
Rubber—one layer	1,993	2,500	1,200	750*	960	600	2.7

* One layer.

Relative Impulse Strength of Rubber, Cambric, and Paper-Insulated Cable

All tests were made on the same size cable, number 6, $^6/_{64}$-inch wall insulation, lead sheath. The rubber was a typical 60 per cent, the black varnished cambric was typical of the best available four years ago, and the paper was kraft of about 300 seconds Gurley air resistance saturated with a typical oil used for the solid type of paper cable. Generator 1 was used with the 1x10 wave. The results in volts per mil wall are given in table IX.

The impulse strength of the paper is nearly double that of the rubber and cambric but it is interesting to note that here again as in table VII there is good correlation between impulse and 60-cycle strength. The insulations of high 60-cycle strength show correspondingly high impulse strength.

Although the impulse strength of the rubber in table IX is 40 per cent less than that of the paper, one of the rubber compounds in table VII is only 17 per cent less than the paper in table IX. Since the 60-cycle strength of the best rubber compound in table VII does not represent the highest obtainable with rubber, this suggests that it might be possible to make rubber compounds that are equal to paper in impulse strength. Because of the compounding variables the dielectric strength of rubber is subject to control over a much wider range than that of either cambric or paper.

Table VII. Impulse Strength of Different Rubber Compounds

Compound	Impulse Strength (Volts Per Mil)			60-Cycle Strength (Volts Per Mil)			Ratio, Impulse to 60 Cycle (Average)
	Average	Maximum	Minimum	Average	Maximum	Minimum	
Code	880	920	840	315	320	310	2.8
AO	870	990	690	255	260	250	3.4
Ozone resistant	1,090	1,290	920	359	400	290	3.0
Performite	740	830	700	275	280	270	2.7
AA-35	840	970	700	347	360	320	2.5
60 per cent S. C.	1,137	1,500	710	375	450	300	3.0
60 per cent H. V.	1,600	1,665	1,535	470	510	430	3.4
Anhydrex	1,340	1,460	1,360	338	365	320	4.0

Table VIII. Impulse Strength of Rubber-Insulated Tree Wire

	Average Impulse Strength				Average Wet 60-Cycle Strength		Wet Ratio, Impulse to 60 Cycle
	Dry		Wet				
	Kv	Volts Per Mil	Kv	Volts Per Mil	Kv	Volts Per Mil	
Fiber tape	107	1,370	89	1,140	24.4	313	3.6
No fiber tape	96	1,230	86	1,100	22.3	286	3.8

Impulse Strength of Rubber, Cambric, and Paper Sheets

All tests were made between two-inch-diameter brass electrodes with rounded edges, using generator 1 with the 1x10 wave. The paper was kraft of about 2,000 seconds Gurley air resistance, in layers of 0.005 inch, saturated in paper-cable oil. The varnished cambric was in 0.012-inch layers of the same type as that in table IX. The rubber was 60 per cent in 0.050-inch layers. The test results in volts per mil are given in table X.

As would be expected these results are seen to be considerably higher than those on the insulations in cable form. The strength of the sheet rubber is some 50 per cent higher than that of the thinner rubber cables tested. Similar to the cable insulation the paper sheet strength is about double that of the rubber sheet, but unlike the cable insulation the sheet cambric strength is nearly as high as the paper sheet. On sheets the ratio of the impulse strength to the 60-cycle strength is seen to be about 2.6.

Properties of Impulse Faults in Rubber and Cambric Insulation

The above results indicate that in most cases the impulse strength of rubber is in general as high as that of cambric. This does not agree with our general experience that rubber is somewhat more subject to lightning damage in service than is cambric. For this reason we made a few comparisons of the proper-

Table XI. Properties of Impulse Faults in Rubber and Cambric Insulation

	Rubber Sample	Cambric Sample
Sample 1		
15 kv d-c for 15 min.	OK	OK
165-kv impulse	Failure	Failure
3 kv a-c for 1½ hours	OK	OK
D-c dielectric strength* (kv)	6.2	10.1
A-c dielectric strength (kv)	3.8	5.2
Sample 2		
165-kv impulse	Failure	Failure
A-c dielectric strength (kv)	4.3	5.8
Sample 3		
A-c dielectric strength (kv)	45 (480 volts per mil)	31 (290 volts per mil)

* One-fifth-ampere fuse.

Table XII. Low-Energy Impulse Faults in Rubber

Sample 1

Impulse failure at 70 kv. No flash but glass broken
No location with magnifying glass
OK on 1,000-volt Megger
Fault picked up at 4 kv d-c by 0.6-milliampere kenotron
Fault less than 0.5 millimeter in diameter

Sample 2

Impulse failure at 60 kv
Fault located to within two inches by aid of flash
No location with magnifying glass
Fault picked up at 3.4 kv d-c by 0.6-milliampere kenotron
Fault less than 0.1 millimeter in diameter

ties of these faults in the two types of insulation.

The tests reported in table XI were made on two-foot samples of number 6 solid, $^{8}/_{64}$-inch wall of insulation lead sheath. The impulse tests were made on generator 1 with the 1x10 wave.

As shown in table XI both number 1 samples withstood 15 kv direct current for 15 minutes without failure but failed when subjected to a 165-kv impulse. After this both samples withstood 3 kv alternating current for 1.5 hours without failure, when they were removed from test. Since this voltage is more than double the operating voltage of each cable it shows that both faults would have remained in service for a considerable period after the impulse failure. Finally each fault was broken down with direct current. Although this test was made with a one-fifth-ampere fuse in series with the sample each fault was burned out to some extent. In spite of this burning each fault showed an a-c strength more than twice the operating voltage. It is interesting to note that the cambric fault gave considerably higher dielectric strength on both the d-c and a-c breakdown tests. That is, both faults would have withstood the operating voltage for some time after the impulse failure, possibly indefinitely, but the cambric fault was less likely to cause a service failure than the rubber fault. The tests on the number 2 samples confirm this comparison.

This indicates that an impulse fault in cambric is less likely to cause a service failure than one in rubber but that in either insulation the impulse failure may not cause a service failure for days, months, or even years after the impulse failure. In confirmation of this we have found lightning faults in rubber-insulated cable that was taken from service after a perfect operating record. The presence of water undoubtedly would increase the probability of an impulse fault failing in service; that is, the cable may fail during the first rainstorm after the lightning, or it may never fail.

Incidentally, these tests bring out one advantage of high-voltage d-c testing. It is a most effective means of developing any lightning faults that may be in the cable.

Table XII gives additional data to indicate the small size of a low-energy impulse fault. Each sample was one foot of number 1 4,$^{8}/_{64}$-inch wall of rubber, tested under water in a glass jar, using generator 1 and the 1x10 wave.

The results show that the size of such a fault may be extremely small, too small to be visible on the outside surface of the rubber. Even after being burned out by the kenotron the faults were very difficult to locate visually.

Conclusions

Within the limits of the tests made, the following conclusions appear justifiable:

1. The impuse strength of cable insulation is not critically affected by the shape or polarity of the impulse, the type of outer electrode, or the length of the specimen.

2. In walls of $^{8}/_{64}$ inch or thereabouts the impulse strength of rubber-insulated cable may be from 700 to 1,600 volts per mil depending on the type of rubber compound. The strength decreases with increasing wall.

3. The impulse strengths of varnished-cambric and oil-paper insulated cables are about 1,000 and 2,000 volts per mil respectively.

4. The impulse strength of cambric and oil paper insulated cable is between three and four times the 60-cycle strength but that of rubber-insulated cable may be anything from two to four times the 60-cycle strength.

5. In sheets between two-inch disks the impulse strength of rubber is some 50 per cent higher than that of rubber cable insulation of the same wall. Similar to cable insulation the sheet paper is about double the sheet rubber but unlike cable insulation the sheet cambric is nearly as high as the paper.

6. The fiber tape and braid in rubber-insulated tree wire do not add appreciably to the dielectric strength impulse or 60 cycles of the wire, particularly when wet.

7. An impulse fault in cambric insulation has higher a-c strength than one in rubber insulation but the a-c strength of either fault may be sufficient to withstand the operating voltage for long periods of time.

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Discussion

R. B. McKinley (nonmember; General Electric Company, Schenectady, N. Y.): We have also made some impulse tests on rubber insulation. Most of these were on 30 per cent and ozone-resisting compounds.

Our test results were in agreement with those presented by Messrs. Davis and Eddy in the fact that the impulse strength in volts

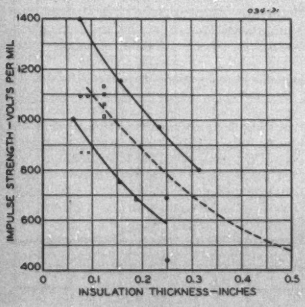

Figure 1

per mil decrease rather rapidly with increasing wall thickness. Some of the answer for this might be due to the mechanics of manufacture in that it is more difficult to hold the heavy insulation walls perfectly centered during the vulcanization period, although this was checked carefully and the fact that there might be greater difference in the degree of "cure" throughout the insulation wall. That the degree of vulcanization does have some effect is indicated by a few tests we have made.

Our values, together with some of those reported in the Davis and Eddy paper, have been plotted, and I believe the chart is worthy of a little study, as it might offer an additional reason why general experience indicates that rubber is more subject to lightning damage than varnished cambric. Furthermore, it might also indicate the advisability of further study before adopting rubber insulation for voltages in the range from 22 to 35 kv in places exposed to severe surges.

The upper curve of figure 1 of this discussion was drawn from values given in table VI of the Davis and Eddy paper. The lower solid curve shows our results obtained on 30 per cent insulation. It is interesting to note how closely the two curves parallel each other throughout the range of thicknesses tested. The points marked by crosses were taken from table VII for 30 per cent class *AO* rubber and indicate how closely the tests agree.

The points indicated by circles or squares are those for the ozone-resisting or oil-base compounds, including insulations of various manufacturers. I have drawn the dotted curve in parallel to the other two curves and extrapolated to one-half-inch insulation thickness merely to investigate what the possibilities might be at the higher voltages. The true curve for ozone-resisting insulations might of course be much different from the dotted curves shown, although the small amount of information that we do have does indicate that these insulations also have lowered impulse strength with increased thickness.

I have calculated the breakdown voltages for 26-kv cable with varnished cambric, paper, and oil-base insulations. The thicknesses of insulation for 26-kv grounded neutral for the three insulations would be 0.422 inch, 0.297 inch, and 0.469 inch, respectively. Using 1,040 volts per mil for the varnished-cambric insulation in accordance with the Davis and Eddy results, 1,600 volts per mil in accordance with the Foust and Scott paper, and 500 volts for the oil-base insulation as indicated by the extrapolated curve, the following values would be obtained:

Varnished cambric	439 kv
Paper	475 kv
Ozone-resisting	235 kv

I do not want to leave the impression that I am saying rubber insulation will not operate at 26 kv. There are cases in service to disprove that, but I do believe the results given in this paper show us something that bears looking into further before we extend the use of high-voltage rubber too rapidly.

C. M. Foust (General Electric Company, Schenectady, N. Y.): The work reported by Messrs. Davis and Eddy is interesting and valuable. On several occasions I have conducted similar tests on impulse breakdown strength of rubber insulation and have reached conclusions in agreement with the authors on most points. My general level of voltages and gradients for various wall thicknesses agrees with the figures given in the several tables of the paper and breakdown gradients decreased with increasing thicknesses as shown in table VI.

I am puzzled by the results shown in table V on the effect of specimen length. In view of the variation in breakdown between samples at any one specimen length, it seems reasonable that the impulse strength for the longer specimens should decrease as the 60-cycle values do. It is a little disconcerting to have the impulse 60-cycle breakdown ratio vary with specimen length. I am wondering if in some of the tests described an appreciable portion of the output voltage of the generator might not have been across the ground-electrode water resistance, particularly for the longer test pieces of high capacitance. At a breakdown voltage of 90 kv reached uniformly in one microsecond across a capacitance of 0.0024 microfarad, the current through the water would be about 200 amperes. At anything less than, say, ten ohms, this would be inconsequential. However, at higher resistances an appreciable resistance voltage would be obtained, resulting in reduced voltage across the insulation particularly for breakdown values occurring before crest.

Our tests using the cathode-ray oscillograph with the viewing and recording each applied wave showed breakdown to be occurring before or on the wave crest. In many cases final breakdown indicated by the chopping of the wave, occurred substantially below the previously applied crest-voltage level and on the rising front. When these actual chopped wave values are taken a breakdown-voltage value some ten per cent below the full-wave value is obtained.

In my test only one voltage wave was applied at each level while the authors applied two. Indications of occasional damage without breakdown suggest that some five applications at each level would provide a more representative breakdown value.

The authors have described tests wherein successive applications of direct, impulse, and direct voltage were applied with the conclusions derived therefrom that a cable having an impulse breakdown may remain in service for some time. However, in service the normal excitation would usually be on at the time of impulse failure and immediate follow-up of short-circuit current would certainly result in many cases.

Herman Halperin (Commonwealth Edison Company, Chicago, Ill.): Information on the surge breakdown strength of insulated power cables has been rather meager, and so the data on a variety of insulations from Davis and Eddy and on impregnated-paper insulation from Foust and Scott are quite welcome. In general, data on surge strengths of various insulations have been appearing in relatively good quantity in recent years in this country and abroad, particularly at the Paris meetings of the International High-Tension Conference.

Troubles in cables due to lightning have been pretty much confined to the lower-voltage cables connected to overhead systems. Dielectric strength to withstand surges, either due to switching or due to

lightning, may, however, be the limiting factor in determining minimum safe insulation thicknesses for the higher types of insulation in extra-high-voltage cable. Surge strength to withstand switching surges was a factor, for example, when in Chicago we adopted, in 1935, oil-filled insulation of 315 mils thickness for the 100,000-kva 66-kv lines, whereas with the solid-type 66-kv cable with about 688 mils of insulation the surge strength was greatly in excess of requirements.

The industry would, I believe, be interested in data obtained by others similar to the data on a number of variables obtained by Davis and Eddy, since such data are comparatively rare.

The rest of this discussion applies to impregnated-paper insulation for particularly power cables.

The average surge strength of 1,600 volts per mil found by Foust and Scott agrees reasonably well with the results of Held and Leichsenring[1] who reported 1,770 to 2,400 volts per mil average surge breakdown stress and with the average value of 1,920 volts per mil given in the paper by Davis and Eddy presented at this convention.

Some discrepancies between the results of various investigators probably are due to the effects of different variables which have not been well established as yet. It appears, for example, that higher breakdown values are obtained with small laboratory samples than with complete cables. It is gratifying, therefore, that the tests reported in the Foust-Scott paper were all made on complete cables. In a 1933 AIEE paper, Mr. Scott reported the results of surge tests on 15 mils of impregnated-paper insulation between flat electrodes. The surge strength for these samples was about 3,400 volts per mil. J. Borel[2] reported last year results of surge tests on small laboratory samples with concentric electrodes and insulation thicknesses of 40 to 160 mils. He obtained surge breakdowns at a maximum stress of about 2,900 volts per mil and an average stress of about 2,500 volts per mil. Also the results of Davis and Eddy confirm the conclusion that much higher surge strength values are obtained for small laboratory samples than for complete cables. They report for the former an average impulse strength of 3,890 volts per mil as compared with 1,920 volts per mil for the complete cables.

The relative surge strength of various types of cable still seems somewhat indefinite, even after considering the two papers. In a paper by Buss and Vogel,[3] published in 1935, the following tentative values were given: solid-type cable, 2,540 volts per mil; oil-filled cable, 2,000 to 2,540 volts per mil; pressure cable, 2,540 to 3,000 volts per mil. While these results indicate higher surge strength of pressure cable than for solid-type or oil-filled cables, Mr. Scott stated in his 1933 AIEE paper that "at power frequencies and under long time application of voltage there is a considerable increase in endurance strength of oil-treated insulation at pressures of several atmospheres. Under impulse stresses, however, practically no benefit is derived from increasing pressure. The effect of pressure on dielectric strength is greater the longer the time of voltage application, being negligible for the impulse voltage tests of only a few microseconds duration." On the other hand, Borel found an increase in surge strength with increasing pressure.

Other questions of interest are the effect of thoroughness of impregnation and of aging on the surge strength of cables, the cumulative effect, if any, of repeated surges, the surge strength of three-conductor belted cables as compared with single-conductor cables, and the shape of the time-lag curve. It is realized that tests of this type are cumbersome, and progress in answering these questions will be of necessity slow.

It is noted that all tests were made by Foust and Scott with positive polarity and most tests by Davis and Eddy were with negative polarity. Held and Leichsenring found no effect of the polarity on oil-filled cables but for solid-type cables obtained 5 to 13 per cent higher surge strength for positive waves than for negative waves. The higher lightning voltages are usually negative.

REFERENCES

1. SURGE STRENGTH OF HIGH-TENSION CABLE, paper number 207, at 1939 Paris meeting of International High-Tension Conference.

2. CONTRIBUTION TO THE STUDY OF ELECTRIC CABLE, paper number 202, presented at the 1939 Paris meeting.

3. SURGE TESTS ON HIGH-VOLTAGE CABLES, *V.D.E. Fachberichte*, 1935, pages 61–3.

P. L. Bellaschi and W. L. Teague (Westinghouse Electric and Manufacturing Company, Sharon, Pa.): These papers by Foust and Scott and Davis and Eddy present interesting data on the impulse and 60-cycle strength of insulating materials particularly those used in cables. In testing similar materials and parts and in our experience with the various factors affecting insulation breakdown, we have obtained results which are, on the whole and in principle, in accordance with the findings so ably reported in the papers by Messrs. Davis and Eddy and by Messrs. Foust and Scott. It would lead the discussion too far afield with perhaps no particular profit to attempt a minute comparison of the various findings.

There is a pertinent point which has a practical and a fundamental bearing on the insulation problem. Both papers indicate a volt-time characteristic for the type of insulation tested which is essentially constant down to one or two microseconds. These are in effect the shortest times to which the investigations were carried. The curves of figure 2 of this discussion enlarge on this fundamental question. These curves present the volt-time characteristics of liquid and solid insulation, and of apparatus insulation from the long times down to the very short impulses of 0.25-microsecond duration.

Curve *A* is the characteristic for transformer oil between a disk and a plate; curve *D* is for oil impregnated pressboard for the same electrode arrangement.[1] Curve *B* is the volt-time characteristic of major transformer insulation as applied to high-voltage design.[2] Curve *E* is for turn-to-turn oil-impregnated paper insulation. Curves *D* and *E* are also typical for other insulation, as varnished cloth, etc. While we have no data at this moment on the impulse characteristic for rubber at the very short times, there are no good reasons to suspect that it has a greater upturn at the very short times than in these last two curves.

The degree of the upturn of the volt-time characteristic depends on a number of factors, as the relative amount of liquid and solid insulation which make up the insulation body or structure, the treatment applied to the insulation, the electrode arrangement and insulation of the electrode proper, etc.

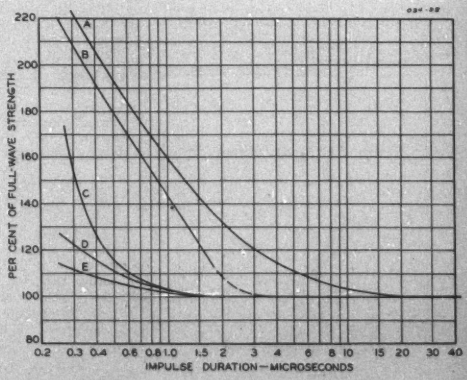

Figure 2. Volt-time characteristics of insulation

A—Transformer oil, one-fourth inch between disk and plate electrodes (reference 1)
B—Transformer major insulation (reference 2)
C—Oil-filled cables (reference 3)
D—Oil-impregnated pressboard. Average for 1/16- and 1/8-inch thickness between disk and plate electrodes (reference 1)
E—Oil-impregnated turn-to-turn insulation. Average values for 0.03-, 0.06-, and 0.12-inch thick paper

Curves *A*, *D*, and *E* apply for repeated applications, which consist usually from 15 to 30 impulses being applied before the point of breakdown is reached. Curve *B* is an endurance curve for hundreds of applications.

Curve *C* (from the test data on cables by Held and Leichsenring) was established from single applications. On the flat part, repeated applications gave voltage values not more than five to ten per cent lower. It is possible that the upturn at the very short times would be lower on repeated applications and that the curve would come nearer to *D*. There are, however, other factors which may account for the substantial upturn of curve *C*, as the presence of oil in relatively good amount in an oil cable. The results of Held and Leichsenring at the longer times apparently differ in one respect from those of Messrs. Foust and Scott, in that the former found the breakdown gradient at the conductor to be a constant.

The additional data on the dielectric strength of cable insulating materials, presented in these two papers, should make it possible to better tie in the relative strength and characteristics of various apparatus, and to this additional extent, give further scope and strength to the general problem of insulation co-ordination.

References

1. Dielectric Strength of Transformer Insulation, P. L. Bellaschi and W. L. Teague. Electrical Engineering (AIEE Transactions), volume 56, page 164.

2. Vacuum Boost Insulation Strength of Transformers, P. L. Bellaschi and F. J. Vogel. *Electric World*, January 1930.

3. The Behavior of High-Tension Cable Installations Under the Effect of Voltage Impulses, Ch. Held and H. W. Leichsenring. Paper number 207, C.I.G.R.E., Paris, June–July 1939.

L. G. Smith (Consolidated Gas Electric Light and Power Company of Baltimore, Baltimore, Md.): The industry is indebted to the authors for the data contained in the papers by Foust and Scott and Davis and Eddy. We have impulse flashover strength of line and station insulators and have available impulse levels of transformers and other apparatus. These data for cable augment the information necessary to design the system insulation levels and lightning protection installations. The impulse breakdown values reported presumably are for new cable. While information for new insulation is a necessary step, the user is also interested in similar data for older cable, after voids have formed, the oil deteriorated, or some "tracking" has occurred in paper cable; the rubber has aged in rubber-insulated cable; or the insulation has deteriorated in varnished-cambric cable. Lightning protection must be designed to protect the cable throughout its useful life. It is realized that obtaining the data presented in the papers involved considerable time and expense; and that the testing necessary to establish impulse strength of insulation as it ages represents even greater costs. However, the suggestion is made at this time as a guide to further research.

In interpreting the data on paper cable, the conclusion is reached that insulation thickness and conductor size has slight effect upon the impulse strength. On the other hand, the insulation thickness appears to have a material effect upon the impulse breakdown of rubber cable. It would be of value to determine the effect of conductor size on both rubber and varnished-cambric insulated cable and the effect of insulation thickness on varnished cambric cable.

It is interesting to note that the type of rubber compound that supposedly possesses the best aging characteristics developed the lowest impulse breakdown. The statement made in the Davis and Eddy paper that an impulse breakdown of rubber or varnished-cambric insulated cable may not result in a service failure is questioned. The 60-cycle tests were made subsequent to impulse breakdown. If normal rated 60-cycle potential had been connected to the cable at the time of the impulse test, it is believed that power follow current would have reduced the fault resistance to the point where normal voltage could not have been withstood.

L. F. Hickernell (Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.): This paper is a valuable contribution to the knowledge of the electrical characteristics of insulated power cables in that it presents, for the first time before the AIEE, impulse-strength data on varnished-cambric and rubber cable insulation. Previous and accompanying papers have been confined to similar data on impregnated-paper insulation. ("Traveling-Wave Voltages in Cables" by H. G. Brinton, F. H. Buller, and W. J. Rudge, AIEE Transactions, March 1933, page 121, figure 7, and "Some Impulse-Voltage Breakdown Tests on Oil-Treated Paper-Insulated Cables" by C. M. Foust and J. A. Scott, AIEE Transactions, volume 59, 1940, pages 389–91.)

Impulse Generators

Referring to "Impulse Generators", it is stated the *impulse* voltage was applied in seven-kv steps. Referring to "Impulse Strength of Rubber-Insulated Tree Wire", it is stated that the *60-cycle* voltage was applied at the rate of three-kv per 15 seconds. In determining values of ultimate breakdown strength, the rate of rise of the applied voltage is important. Generally speaking, the faster the rate, the higher the value obtained. Accordingly, the following questions arise:

1. Were all 60-cycle breakdown tests conducted with the same rate of rise of applied voltage?

2. If so, what was the rate? (That is, does the three-kv per 15 seconds, stated under "tree wire" apply to *all* 60-cycle tests?)

If the rate of rise were three-kv per 15 seconds, it should be noted that the values in the paper cannot directly be compared with data obtained from factory test reports which generally are governed by ASTM designation *D*470-37*T*. Section 13 of this standard specifies a rate of rise of three-kv per second.

Effect of Electrode Surface on Impulse Strength

Table IV shows the results obtained with the following means of providing the grounded electrode:

1. Lead sheath
2. Immersion in salt water
3. Lead foil wrapped over insulation

It is concluded that the method used has no effect on the results. Inasmuch as (1) is unaffected by the time of immersion whereas (2) and (3) are, it would seem that the time of immersion prior to test was relatively short and should be so stated. In any event, the limit of the time of immersion for which this conclusion holds should be stated.

Effect of Insulation Thickness on Impulse Strength

Table VI indicates a decrease in unit impulse strength with increasing wall thickness which is the basis for the statement, "The same tendency has been shown by the a-c strength of many insulations." While it is generally true that the unit *60-cycle* strength decreases with increasing thickness, most investigators have found that the unit *impulse* strength of insulations in general is practically proportional to their thickness; or as popularly stated, "an inch is an inch" insofar as impulse strength is concerned. This has been demonstrated by many investigators for porcelain insulators and to a more limited extent for impregnated-paper insulation (see references in first paragraph). Therefore, it would seem that if the data in table VI are truly representative after confirmation, the conclusion should be confined to *rubber* insulation.

Effect of Compound Type on Impulse Strength

In table VII, the following average 60-cycle strengths are shown for three types of rubber insulation:

Rubber Compound	60-Cycle Strength (Average) Volts Per Mil
Code	315
ASTM type *AO*	255
Performite	275

While no claim has been made generally that type *AO* or Performite are high-voltage insulations, it is rather surprising to note that the authors obtain lower dielectric strength with their type *AO* (30 per cent) and Performite (35 per cent) than they do on their Code (20 per cent) compounds. It

Table I

Table Number	Insulation	Conductor (American Wire Gauge)	Insulation (64ths)	Outer Electrode	Impulse (Average Volts Per Mil)
VII	Anhydrex	6 or 8	5 or 6	(Salt water)	1,340
IX	Anhydrex	6	5	Lead	1,143
				Ratio =	1.17

is not believed that this is truly representative of the relative rating of these types of insulations in the industry in general.

Relative Impulse Strength of Rubber, Cambric, and Paper-Insulated Cable

Rubber. The text states these tests were conducted on a "typical 60 per cent rubber," table IX indicating this to be "Anhydrex" rubber. It would be interesting to know the reason for the lower impulse strength of Anhydrex rubber shown in table IX as compared with table VII, as shown in table I of this discussion.

Paper. It would be of interest to know the thickness of the paper tapes as well as the Gurley air resistance. It may be pointed out that 300 seconds air represents a *low* density paper as judged by modern standards of paper-cable manufacture. This paper is quite different from that used for the sheet tests reported under "Impulse Strength of Rubber, Cambric, and Paper Sheets" (five mils, 2,000 seconds Gurley).

The term "typical oil" is rather indefinite in view of the present use of naphthenic and paraffinic-base oils from different fields, with or without rosin, by the several manufacturers.

Control of Rubber. The authors suggest the possibility of making rubber insulation equal to paper in impulse strength because the "compounding variables" in rubber are subject to a wider range of control than in paper or cambric. In this endeavor, the well wishes of the entire industry will be extended to them. However, it would seem only fair to point out that both theory and present experience would indicate this to be a most difficult if not impossible assignment. In general, dielectric strength seems to follow the same laws as mechanical strength; namely, a laminated structure is stronger than a solid structure. Rubber is a more or less solid material; paper and cambric are laminated structures.

While it is true that there are more "compounding variables" in rubber than paper and cambric and hence more factors to juggle, there are also more chances for things to go wrong and the manufacture is on the whole less subject to control. A recipe for a rubber insulation will contain from five to ten ingredients compared with two for paper or cambric. The advantage of this flexibility is offset by the difficulty of controlling the quality and dispersion of so many ingredients (gum rubber itself is practically impossible to control). In addition to formulation, a rubber compound must be mixed, rested, warmed, tubed or stripped, and vulcanized. While these operations are subject to some control, the degree does not approach that capable with paper insulation. A paper cable can be closely governed by actual measurement of its electrical characteristics during its processing. Accordingly, it is doubtful if a commercial length of rubber cable can be made foot by foot of as high and uniform quality as paper cable simply because the manufacturing processes are inherently not subject to as fine a degree of control.

Properties of Impulse Faults in Rubber and Cambric Insulation

The conclusion that the 60-cycle strength of either rubber or cambric is sufficiently high after an impulse fault to prevent a *service* failure for some time is not substantiated by the test data in table XI. In actual service, a lightning fault is generally followed by a 60-cycle power arc which burns the insulation and greatly lowers the a-c strength. This service condition is not simulated in a shot from an impulse generator with no power follow-up.

E. W. Davis and W. N. Eddy: Mr. McKinley's calculated comparison of the impulse strength of 26-kv walls of varnished cambric, paper, and rubber leaves the rubber a poor third with only one-half the impulse strength of paper or cambric. We cannot agree that this comparison is justifiable, for three reasons:

1. His determination of the ozone-resistant rubber strength by extrapolation to 0.469-inch wall is too speculative with the available data limited to six points between 0.075- and 0.125-inch wall.

2. His assumption that the cambric strength at 0.422-inch wall is as high as that at 0.094-inch wall does not appear justified in the complete absence of data. Cambric may not be any more similar to paper in impulse strength than in other electrical properties.

3. For a 26-kv cable we would use a 60 per cent high-voltage rubber (with proper ozone protection) which in table VII has an impulse strength 50 per cent higher than that of the ozone-resistant rubber.

Both Mr. Foust and Mr. Hickernell question the significance of the data in table XI because the impulse faults were not produced with the 60-cycle and impulse voltages superposed as they probably would be in the field. We do not believe that this limitation is serious. Considerable data from laboratory tests on cable taken from service, from field tests on installed cable, and from customers' records indicate that impulse faults may be formed in the presence of continuously applied 60-cycle voltage and the cable still remain in service for an indefinite period after the lightning damage. A typical field experience is that the breaker opens during the storm but is immediately reclosed with no further trouble. Sometimes there is not even this indication of lightning trouble. Hours or even days after the storm the cable fails. Subsequent tests show that in addition to the developed fault causing the failure the cable often contains other faults having properties very similar to the laboratory-made impulse faults described in tables XI and XII.

Mr. Foust is puzzled by the constant impulse strength shown in table V with increasing sample length. We share his point of view. In fact we investigated the matter in more detail than is indicated in the paper and intend to continue this investigation at the first opportunity. In connection with his discussion of the voltage drop across the water the following testing details lead us to doubt that an appreciable portion of the impulse is taken by the outer cable electrode.

All water was salt water. Tests were made in water on samples from one length at one, two, five, and ten feet from another length at one, two, five, and ten feet and from another length at two and five feet. Tests were made on leaded samples (not in water) from another length at 10, 20, and 40 feet. None of these 70 tests show any appreciable effect of the length. They are all well represented by the values in table V.

With reference to Mr. Hickernell's questions, in the order given;

1. All 60-cycle breakdown tests were made with the same rate of voltage increase, three kv per 15 seconds. Our experience indicates this rate to be the most practicable in general for such purposes. We have been using it more than 12 years.

2. In connection with table IV we do not understand his statement that method 3 (lead foil wrapped over insulation) is affected by the time of immersion. Only method 2 (immersion in salt water) is affected by the time of immersion. In general our tests indicate that there is no appreciable influence of immersion time in salt water on dielectric strength for several months. Since none of the samples reported in the paper were immersed in the salt water more than one hour, we believe there is no influence of immersion time.

3. We agree that any conclusion from table VI should be limited to rubber insulation. In fact we feel that the wording of the paper makes this quite obvious.

4. With reference to table VII he questions the relative 60-cycle strengths of Code, *AO*, and Performite compounds (given as 315, 255, and 275 volts per mil respectively). Our tests indicate that these differences in dielectric strength are too small to be of any significance. These particular values were obtained on the particular wire used for the impulse tests. Hundreds of other tests made by us on these three compounds indicate no significant difference in 60-cycle strength among the three of them.

5. He questions the slight difference in the impulse strengths of Anhydrex shown in tables VII and IX. We have a good many different Anhydrex compounds. As it happens, that in table IX showing a strength of 1,143 volts per mil is one of the earlier compounds while that in table VII (1,340 volts per mil) is a more recent compound. As stated in the paper, all the tests were not made at the same time.

7. The tapes in the paper cable were three-fourths inch wide by 0.007 inch thick. The oil was paraffin-base, without rosin.

8. Without attempting a detailed discussion of the control of rubber we may say that we are unable to share Mr. Hickernell's pessimism in this respect, because we have too much evidence that the physical and electrical properties of rubber compounds can be kept under close control.

Co-ordination of Power and Communication Circuits for Low-Frequency Induction

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WHERE power and communication facilities are in proximity, electromagnetic induction from the power system may cause disturbances in the communication system. The avoidance or minimizing of such disturbances, with due regard to the service and other needs of both systems, is a problem of co-ordination, which is conveniently divided into two parts, one dealing with low-frequency inductive co-ordination and the other with noise-frequency co-ordination.

The present paper undertakes a general examination of the problem of low-frequency inductive co-ordination in the light of developments during the past decade. The situation as it existed at the beginning of the decade is to be found well set forth in a paper presented in 1931 at the AIEE winter convention by R. N. Conwell and H. S. Warren. The present paper, like its predecessor, derives from the work of the Joint Subcommittee on Development and Research* of the Edison Electric Institute and the Bell System. It is largely concerned with induction from currents due to power system ground faults and the transients which accompany such faults. It gives relatively little attention to continuous low-frequency effects since, up to the present at least, such effects have not been a primary concern in the low-frequency co-ordination of commercial power circuits and Bell System communication circuits.

A further object of the paper is to outline the various factors that require consideration in practical situations and to discuss their significance under present-day conditions. To provide necessary background for this, recapitulations of fundamentals are included at appropriate points. Detailed discussions necessarily omitted from the paper itself are to be found in the papers listed in the bibliography, many of which, particularly the Conwell-Warren paper,[1] contain further references.

A situation which calls for measures of inductive co-ordination ordinarily involves a parallelism or quasi parallelism of sections of power and communication lines. The possibility of disturbance by electromagnetic induction from the one system to the other depends upon certain characteristics of the power system (called "influence factors") and also upon such characteristics of the communication system as affect its liability to disturbance ("susceptiveness factors"). Of equal significance are the "coupling factors", which determine the electromagnetic coupling between the two systems. Figure 1 is a diagrammatic representation of the main factors of these three groups in a low-frequency induction situation. Some of these items can obviously be evaluated by calculation or by relatively simple tests, while others do not lend themselves to determination by such methods.

In a low-frequency induction problem, where, as in figure 1, power-system ground-faults are involved, it is customary, first, to calculate the maximum "open-circuit" longitudinal induced voltage. To do this, values are required for the residual power current (that is, in general, ground-return current) to produce this maximum voltage and for the corresponding coupling coefficient. The "open-circuit" voltage thus calculated is next reduced to what may be called the "shielded" maximum longitudinal induced voltage. In this reduction, allowance is made for shielding effects exerted by normally grounded paralleling conductors (ground wires, cable sheaths, etc.) and, in the case of cables, by core conductors. In addition, allowance must be made for additional shielding resulting from longitudinal currents set up in communication conductors normally free from connections to ground, but which become grounded, through protector operation, as a result of the induction. This latter allowance is not ordinarily a simple matter.

It is also usually necessary to know approximately how frequently voltages within specified ranges of magnitude will be induced, and how long they will last when they occur, since the duration of the disturbance affects the energy transferred to the communication system.

Further, although the longitudinal voltages are determining with respect to some kinds of interference, voltages to ground are important with respect to other types. Hence a certain amount of estimating of the distribution of the induced longitudinal voltages with respect to ground is generally desirable.

The final step is, of course, the estimation of the adverse effects of these voltages upon the operation and maintenance of the communication circuits, and the determination where necessary of measures to be taken in either or both systems to minimize the effects.

Valuable information regarding the fundamental factors just discussed has been secured in an analysis[3] of automatic oscillograph observations from 29 actual exposures, which also indicated sources of uncertainty in making advance appraisals of low-frequency induction situations. Comparison of maximum observed voltages with maximum estimated values showed deviations up to about 75 per cent, in both directions. Contributing to these discrepancies were shielding from telephone-line conductors grounded by protector operation, erroneous assumptions of fault resistances, failure of faults to occur at or near locations to produce the maximum voltage, and wave-shape distortion of induced voltage. Duration of induced voltage, distance between protector locations, and number of wires on the telephone line were important in cases of protector grounding. Distribution of induced longitudinal voltage with respect to ground was clearly a matter of importance, although not covered by the available data.

The several factors of influence, coupling, and susceptiveness will now be discussed in order.

Power Systems—Influence Factors

Residual Current Magnitudes—Calculation and Limitation

The magnitude of fault current and its distribution among the various branches of a network may be calculated for any

Paper 40-49, recommended by the AIEE committee on communication, and presented at the AIEE winter convention, New York, N. Y., January 22–26, 1940. Manuscript submitted November 8, 1939; made available for preprinting December 27, 1939; released for final publication February 21, 1940.

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* Referred to hereinafter as the "Joint D. & R. Subcommittee."

1. For all numbered references, see list at end of paper.

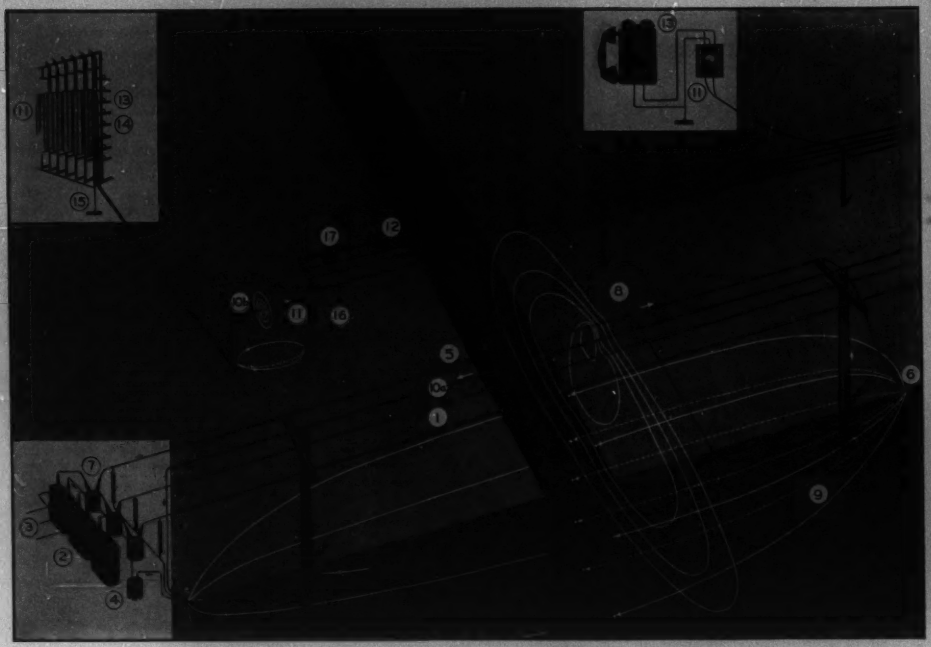


Figure 1. Factors affecting the severity of an inductive exposure

Influence Factors—Affecting magnitude and duration of power-system residual fault current:

1. Line voltage
2. Transformer impedance
3. Impedance of supply to transformers
4. Method of neutral grounding and grounding impedance if used
5. Power-line impedance
6. Fault location and fault resistance
7. Circuit breakers and tripping equipment

Factors (not indicated in drawing) affecting frequency of occurrence in faults include:

Lightning, wind, and sleet storms
Construction practices
Foreign objects in line

Coupling and Shielding Factors—Affecting induced voltage in communication system for given residual current in power system:

8. Separation between lines
9. Earth resistivity (also affects influence)
10a, 10b. Shielding from power-line ground wire and telephone-cable sheath when present

Susceptiveness Factors—Affecting communication system disturbances under given induced-voltage conditions:

11. Protectors—breakdown of blocks and rating of fuses
12. Size, length, kind, and number of wires on line (Some wires may become shielding conductors due to protector-block operation)
13. Low-frequency characteristics of equipment
14. Impedance to ground of terminal equipment
15. Resistance of ground connection
16. Voltage from conductors to ground
17. Voltage between wires (arising from differences of voltage to ground)

(Not indicated)—Location of exposure with respect to nearest protector blocks

assumed fault location and operating setup.[3] For a grounded-neutral system the fault location is usually assumed at the end of the exposure remote from the neutral ground. When line-to-ground fault current may be fed into the exposure from two directions, consideration should be given to the sequence of breaker operation in calculating the conditions for maximum induced voltage. Where ungrounded circuits are involved, it is the usual practice to assume a fault on one phase at one end of an exposure and a fault on another phase at the other end. This condition gives the maximum possible ground current through the exposure and hence the maximum induced voltage. As a rule, this current is larger than the current through the same exposure under the assumption of direct-grounded power neutral.

The impedances of power lines and cables are important elements in determining the magnitudes of residual currents under fault conditions. The most important gaps of ten years ago in data regarding these quantities have been filled in a report of the Joint D. & R. Subcommittee.[4] Impedances in power-circuit neutral-ground connections of course affect ground-fault current magnitudes. Such impedance may be inherent in the grounding equipment or may take the form of an external resistor or reactor, or a Petersen coil (ground-fault neutralizer). Considerations arising from power system design and operation affect the magnitude of neutral impedance which may be used.

In calculating ground-fault currents for use in estimates of induced voltages, significant errors may be caused by failing to take account of fault resistance. This, and other fault characteristics of interest, have been studied by the Joint D. & R. Subcommittee with the cooperation of a number of power companies.[5,6] Data were collected by means of automatic oscillographs from 11 operating power systems, having a total of about 2,800 circuit miles of transmission line at voltages ranging from

26 to 220 kv. The periods of observation were from $1\frac{1}{4}$ to $5\frac{1}{2}$ years. For one-line-to-ground faults, the most frequently occurring apparent fault-resistance, irrespective of fault location, was found to be about 20 ohms (5 ohms for faults at stations), with no great difference as between lines supported on steel structures and on wood structures. However, the studies did not include any lines designed for maximum utilization of the impulse strength of wood.

Since the installation in 1931 of two Petersen coils on a 140-kv system,[7] about 30 other Petersen coils have been installed in this country. With a given arrangement of coils, the residual current in a given exposure, and consequently the induced voltage, is practically independent of fault location. With a directly-grounded or an isolated power system, the induced voltage depends upon the relative locations of fault and exposure, and may vary over a wide percentage range. In grounded-neutral systems, residual currents large enough to make limitation desirable for inductive co-ordination purposes usually occur only where the neutral is grounded either directly or through a low impedance, and large reductions are obtainable through the employment of a Petersen coil.

Line outages preventable by Petersen coils are mainly those due to lightning flashovers. To clear faults not extinguished by the coil, recourse is usually had to short-circuiting the coil, either directly or through an impedance, and relaying out the faulty section of line. Unless a fairly high impedance is used, the residual current would usually be quite large under this condition. But the proportion of all faults that can be cleared without by-passing the coil (reported as from 70 to 90 per cent in various cases[8]) is sufficient to be of real value, even when no impedance is used in series with the by-pass breaker.

From the standpoint of inductive co-ordination, other types of neutral impedance, such as resistors, can be used for current limitation, and their status does not appear to have changed in the past ten years or so. Fault-current limitation has certain advantages from the power operating standpoint, for example, in limiting voltage dips, possible loss of load, and shock to system during faults,[7] and for improving transient stability.[9] Against these advantages, certain disadvantages have to be weighed, if the neutral impedance is to be high enough to have a large effect in most low-frequency induction cases. These questions center mainly upon dynamic overvoltage and the closely related matter of system insulation, and upon relaying.[10]

Dynamic overvoltages vary over a power system because of the flow of residual current through line impedances. In figure 2 a few results are shown from a recording oscillograph study of dynamic overvoltages on overhead systems under operating conditions.[11,12] The percentage of observed cases in which the voltage exceeded twice normal was about 64 for the isolated system, about 5 for the system grounded through Petersen coils, and about 34 for the resistance-grounded system (75 ohms). These records from operating systems were in general accord with the results of staged tests.[13] No evidence was found of the building-up of high sound-phase voltages, such as have been inferred to be possible from theoretical studies of the "arcing-ground" phenomenon. The view has recently been expressed by other investigators that such a voltage build-up is not to be expected if the arc path is between fixed contacts in open air, as in the case of an arc to ground on an overhead line, but that it

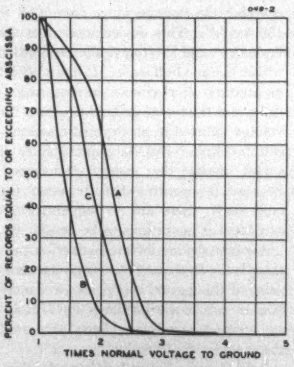


Figure 2. Dynamic overvoltages—magnetic-oscillograph observations on operating systems

A—800-mile 140-kv isolated system
B—274-mile 140-kv Petersen-coil system
C—158-mile 26-kv 75-ohm resistance-grounded system

may occur if the arc occurs in a confined space[14] or between breaker contacts whose separation is increasing.[14,15]

Questions concerning system insulation[16,17,18] may arise when it is proposed to apply a relatively high neutral impedance to a system previously operated with neutral grounded directly. The nature of these questions can be indicated briefly by recalling that a lightning arrester must operate at an impulse voltage amply below the insulation level of the protected apparatus and still not operate or pass current on dynamic voltages likely to be impressed upon it by power sources in the system. While there are many factors to be considered in suiting lightning-arrester protection levels to the insulation levels of equipment, a considerable improvement during the past decade in lightning arresters, together with more detailed knowledge of their characteristics, has somewhat simplified this matter.[19]

Relaying questions involved in neutral impedance applications to systems previously operated with direct ground connections[10] include the possibility of changes in ground relays or the adoption of ground relaying if not previously used, additional potential transformers (when ground relaying is not already in use), possible changes in bushing current transformers, and in some cases, a change to a different relaying system in some portions of a network (to maintain proper selectivity). Ground relaying frequently presents difficulties for systems grounded at more than one point through high impedance.

Frequency of Occurrence and Duration of Ground Faults

The frequency with which induced voltages of various magnitudes may occur in an exposed communication system depends, first, upon the frequency of occurrence of ground faults in the power system and, second, upon their distribution with respect to the locations of exposure and power sources. In most cases, appraisals of these factors are largely matters of judgment. Valuable guidance is usually obtainable from operating experience on the power system or similar systems in the same locality, and from consideration of the character of line construction, connected line mileage, and number and location of neutral grounds. Duration of ground faults can usually be approximated well enough from relay and circuit breaker characteristics.

A simple illustration of the bearing of the relative locations of exposure and power source upon the frequency of occurrence of induced voltage is given in figure 3. In diagram (*A*) the exposure is at an unfavorable location—practically every ground fault would result in residual current through the exposure. On the other hand, an exposure located as in diagram (*B*) would be appreciably affected only by the faults between stations *B* and *C*. In diagram (*A*), it would be advan-

tageous, if practicable, to transfer the neutral ground to station (*B*). Moreover, this would not increase the number of cases of induced voltage in the exposure of diagram *B*, but would probably increase the voltages themselves.

In studies already referred to,[5,6] a large amount of data was collected regarding the characteristics of ground faults. As to frequency of occurrence there was considerable variation among systems (from 5 to 60 faults per 100 line-miles per year, averaged over the periods of observation), and also from year to year on a single system. Lightning was assigned as the known or probable cause of from 50 to over 90 per cent of the faults, depending on the system. On the average, some 10 per cent of the faults were cleared in about 10 cycles, and about 10 per cent required two seconds or more for clearance. The percentage of faults involving each of two phase wires and ground, but at different points, was small—from about one-half per cent to about six per cent in three systems for which data were available. This point is of interest in the use of neutral impedance for inductive co-ordination, since, if an exposure lies between the two fault points on different phase wires, a high induced voltage may result, the neutral impedance being ineffective for limiting ground current in this situation.

In the past ten years, the importance of direct strokes in the problem of protecting transmission lines from lightning has become fully recognized. This has led to a series of investigations which have greatly increased our knowledge of lightning,[20,21,22] and to the development of several methods of preventing interruptions to service from lightning. Measures for preventing ground faults or power follow-up after spark-over, or for limiting the duration of dynamic current to ground faults are directly helpful in low-frequency inductive co-ordination. In the remainder of this section brief comments are made on the developments that seem most significant from this point of view.

The use of ground wires on steel-tower lines results in a substantial reduction in ground faults from lightning.[23] The combined use of counterpoises and ground wires has given further improvement where tower-footing resistance or earth resistivity is high.[23,24] Where the counterpoise is continuous, it, as well as the ground wires, makes a further contribution by reducing coupling coefficients.

Possible improvements in line operation through the use of the insulating properties of wood,[25,26] while perhaps somewhat less attractive than they appeared some ten years ago, have also resulted in reduction of frequency of occurrence of faults. Quite recently renewed interest in the subject has led to a comprehensive experimental study of fundamental factors.[27]

The protector tube (expulsion protective gap), for controlling lightning flashovers on power lines, first used commercially in 1931–32, is finding increasing application, and has been used on lines covering the voltage range from 13.8 to 138 kv.[28,29] This device interrupts the flashover and restores the insulation within about a half cycle. It has no effect in limiting short-circuit current magnitude, and thus none in holding down the voltage induced in an exposed communication circuit. But its great rapidity of action limits the energy transferred. Because it operates directly upon the fault itself, there are no sequential circuit-breaker operations to be considered.

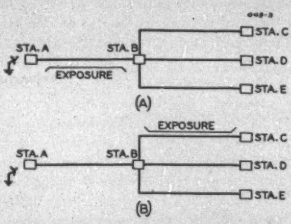


Figure 3. Relative locations of exposure and grounded sources of power—illustrative diagrams

Another device for arc-extinction purposes is the Petersen coil. From the viewpoint of this paper, it is perhaps of more interest as a means for limitation of residual current, and has been discussed above under that heading.

Relay and circuit-breaker developments have been toward substantially higher speeds of operation, both for new installations and in the modernization of existing installations. These developments have made available breakers with an operating time of about 0.13 second, and quite recently still higher speed (about 0.085 second). These figures do not include relaying time. The exceptional speed of about 0.05 second over-all has been reached in the breakers for the Boulder Dam lines.[30,31] Like "lightning-proof" line construction and the use of expulsion gaps, high-speed breakers have, of course, no effect upon short-circuit current magnitudes. But they have the advantage of not being limited to the clearance of lightning flashovers. As used in combination with high-speed reclosing immediately following high-speed opening of circuit breakers, there will probably be some cases where fault recurrence after reclosure will diminish the inductive co-ordination benefit resulting from the high-speed opening.

From the low-frequency induction standpoint, the most notable improvements in relaying have been increases in speed of response, the further development and use of pilot-channel methods,[32,33,34] and particularly the combination of the two to replace earlier methods of selection, with much greater rapidity of relay action. In some recent applications, the time to energize the breaker trip circuit has been reduced to about one cycle (60 cycles per second) by using high-speed relays in combination with pilot channels,[35] with practically simultaneous relay operation at the two ends of the line section.

These developments in the power art, tending to reduce both the frequency of occurrence and the duration of ground faults, are all favorable to low-frequency inductive co-ordination. From a practical standpoint, the resulting degree of benefit depends upon the extent of use of these developments, and upon which are more widely used, since they are not all equally favorable. These matters, of course, are not static and the actual extent of the resulting reaction upon low-frequency inductive co-ordination is not easy to specify in quantitative terms.

Coupling and Shielding

Coupling

The residual power current, when multiplied by the coefficient of coupling between the power and telephone circuits, gives the open-circuit longitudinal induced voltage in the telephone circuit. In determining this coefficient of coupling, or mutual impedance, the telephone and power circuits are treated as ground-return circuits, regardless of normal conditions of operation as metallic circuits. Coupling coefficients can be determined as precisely as required. Methods of calculation have been considerably advanced, and in preliminary estimates, calculated values are generally used. As a rule, however, expenditures for co-ordination measures should only be made on the basis of test data or experience.

In earlier work, the calculation of coupling coefficients was based on the "equivalent ground plane" theory. This theory was first superseded by one in which ac-

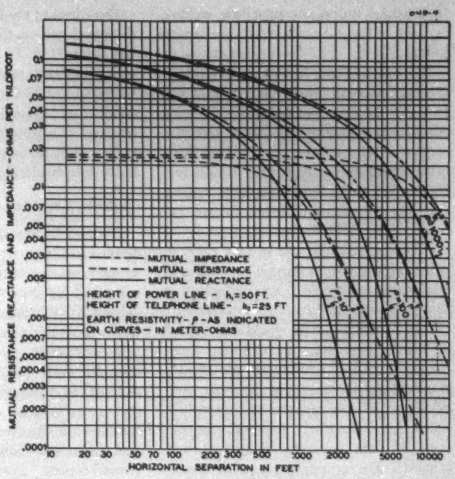
count is taken of the finite conductivity of the earth, assumed to be homogeneous. Another assumption, retained from the earlier theory, is that the primary or "disturbing" circuit is straight and of infinite length. Experimental work interpreted by this theory showed that the earth is frequently far from homogeneous and that its resistivity varies widely from place to place, from 5 to over 10,000 meter-ohms in extreme cases, with corresponding variations in coupling coefficients between circuits. This variation is much smaller at close than at wide separations. For example, at a separation of 50 feet, the 60-cycle mutual impedances between parallel circuits are about 0.36 and 0.63 ohm per mile for resistivities of 10 and 1,000 meter-ohms, respectively. At 5,000 feet separation for the same resistivities the figures are about 0.0035 and about 0.1. These relationships are shown in more detail in figure 4, which is taken from a comprehensive report[38] on coupling between ground-return circuits.

This theory has since been expanded to allow certain departures from homogeneous earth structure,[37,38,39] including a horizontally stratified earth of two layers with different resistivities. In many situations calculated values based on this assumption have agreed well with experimental results.

While the assumption of an infinitely long, straight primary circuit is satisfactory in most practical cases, there are situations in which its application is accompanied by uncertainty. Examples are where the grounding points of the power and telephone lines are in proximity at one or both ends of the exposure, and where breaks in direction occur in one or both of the circuits. Investigation of these "end-effect" phenomena have led to the development of formulas[38,39,40] in which no restrictions are placed upon the lengths of the circuits or the routes they follow, nor upon the relative locations of their end (grounding) points.

In application to practical cases, these "finite-line" formulas require a great deal more labor than the infinite-line theory. Theoretical and experimental study of the need of better precision than the latter affords has not been completed, but work done to date indicates that results based on this simpler theory need scrutiny, particularly if the earth resistivity is high, in cases of proximity of grounding points, and of breaks of direction in either circuit, toward or away from the other, and not compensated by breaks at other points in the opposite direction. If reasonably accurate knowledge of earth

Figure 4. Variation of mutual impedance with separation


MUTUAL RESISTANCE REACTANCE AND IMPEDANCE - OHMS PER KILOFOOT
MUTUAL IMPEDANCE
MUTUAL RESISTANCE
MUTUAL REACTANCE
HEIGHT OF POWER LINE - h=50 FT.
HEIGHT OF TELEPHONE LINE - h=25 FT
EARTH RESISTIVITY - ρ - AS INDICATED ON CURVES - IN METER-OHMS
HORIZONTAL SEPARATION IN FEET

resistivity is available, the effect of proximity of grounding points can be approximated by an easily calculated correction.

In "probe-wire" tests for determining earth resistivity, a number of secondaries (probe wires), parallel to a primary line and at various separations, are used. If, for some of the wires, the separations are too large compared to the length of the primary, errors in the earth resistivity, as inferred from the infinite-line formula, can be avoided by applying relatively simple corrections based upon the finite-line theory.

Earth resistivity depends on the earth structure at the location in question. A compilation of data has been made of earth resistivities in various parts of the country, including correlation of geological formation with resistivity,[41] which will serve as a general guide in preliminary estimates.

Shielding

In this discussion, the word "shielding" is used in a restricted sense to mean a reduction in an induced voltage, this reduction being caused by the action of currents brought into existence by the same primary source that causes the induced voltage. The conductors in which these currents exist are called shielding conductors or shields. They may be associated with the primary system (for example, power line ground wires) or with the secondary system, (for example, telephone cable sheaths) or they may be especially placed purely for shielding purposes. Grounded metallic structures such as water or gas pipes also frequently provide shielding. The effect of extensive networks of such pipes, as in cities, is essentially the same as a lowering of the earth resistivity, and is accounted for directly in the coupling coefficients rather than as shielding.

Results of experimental and theoretical work done on shielding by the Joint D. & R. Subcommittee up to about five years ago have been published in an engineering report.[42] Here methods and data are given for calculating shielding from conductors on open-wire telephone or power lines, from the sheaths of aerial or underground power cables, and from the sheaths of aerial or underground telephone cables with or without tape armor. An approximate method for estimating shielding from grounded-core conductors in telephone cables is included.

The information in this report shows, for example, that the shielding from a three-eighth-inch steel ground wire on a 60-cycle transmission line is 10 per cent or less; two high-conductivity aluminum-conductor steel-reinforced ground wires afford a shielding of about 55 per cent. At 60 cycles, shielding by the lead sheath of a full-size telephone cable is of the order of 50 per cent if the sheath is in good contact with the earth. When the sheath is wrapped with tape armor (two 40-mil steel tapes on the larger-size cables), this figure is increased to 80 or 90 per cent. Shielding due to power cables depends upon the construction and may vary anywhere from 40 to 70 per cent. The effects of buried pipes are usually difficult

to estimate unless the pipes are welded, because of the unknown resistance of pipe joints.

Existing methods for calculating shielding take account where necessary of distributed admittance between shielding conductors and ground. More recently, consideration has been given to the effects of currents in the disturbed conductors themselves. In long telephone cables, such currents are established in part because of the distributed admittances of the core conductors, and in part they result from the use, in normal operation, of equipment connected from conductors to ground at terminals and at intermediate repeater points. The shielding effects* of these currents, particularly those through terminal equipment, are of substantial importance. For example, considering a 50-mile repeater section of full-size cable inductively exposed, the 60-cycle voltage between conductors and ground at the terminals, where the sheath is grounded, may be only some 5 to 15 per cent of the open-circuit longitudinal voltage, that is, the induced voltage with the effects of all shielding currents, both in the sheath and in the core, eliminated. At points away from terminals, considerably larger voltages may exist between conductors and sheath and more particularly between conductors and ground, when as a result of two-directional power current feeds, shielding effects may be partially cancelled. In construction and maintenance work, a part or all of the core conductors may be open, eliminating or reducing shielding currents in them. In this case, voltages across breaks in conductors are important, as well as voltages to sheath or ground.

The usual methods for calculating reductions of longitudinal induced voltage by shielding assume in effect that in any measurements made, for example to verify the calculations, the potential of a distant ground is taken as reference. However, in cases of very close association between shielding and shielded conductors, of which cables are the best example, the voltage between these conductors (core and sheath, in a cable) is frequently of as much interest as the voltage between some point on the core and a distant point.

* From a different point of view, these effects are merely the voltage drop in the disturbed conductors, resulting, of course, from the currents set up in them by the disturbing field. This voltage drop is a self-impedance drop and the shielding is "self-shielding". When, as in the earlier discussion, the current producing the shielding is in a conductor (for example, the cable sheath) which is not itself one of the disturbed conductors, the shielding is also a voltage drop, but it is due to the *mutual* impedance between the shielding conductor and the disturbed conductors.

Questions of the character of those just discussed are on the current program of the Joint D. & R. Subcommittee. Another matter which is receiving attention is shielding by communication conductors grounded through the operation of protectors. This involves rather difficult calculations, with results liable to considerable error.

Testing Methods

Even with the advances already described in the theory of coupling between ground-return circuits, tests are generally necessary for important situations. Considerable attention has therefore been devoted to the possibilities of simplified test procedures. When lines are available for test, coupling can usually be determined most satisfactorily by a direct measurement of induction at the fundamental frequency, or by measuring the induction into short temporary ground-return circuits (probe wires). For situations in which such measurements cannot easily be made, development work on a d-c method of determining earth resistivity, using simple, readily portable apparatus has had promising preliminary results. It is expected that a report covering this and other methods will be available before long.

The development of vacuum-tube voltmeters of high sensitivity has been of value in connection with coupling measurements where one circuit is energized with a small current and the voltage induced in paralleling exploring wires is to be measured.

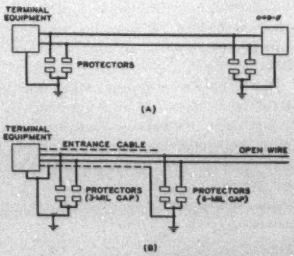


Figure 5. Diagrams to illustrate application of telephone open-space protectors

Susceptiveness

As pointed out in the Conwell-Warren paper,[1] the effects of low-frequency induction upon a communication circuit depend upon the magnitude and duration of the induction. They include service interruption due to protector operation, damage to plant, the possibility of acoustic or electric[43,44] shock, false signaling, and telegraph-signal distortion. Some of these effects, such as interference with signaling, may occur at induced voltages below the protector breakdown value. However, the more serious effects from low-frequency induction are usually associated with induced voltages sufficient to operate protectors.

An interruption to service results from permanent grounding of protectors, which occurs if the discharge current through the protector is not promptly extinguished, or if this current is very high. Protectors are employed as required for the protection of persons, equipment, or property, as at central offices, stations, etc. A simple diagram to illustrate the application is given in figure 5*A*. Where the circuit is in open wire and entrance cable is involved, an additional set of protectors is placed at the junction of the open wire and the entrance cable, as shown in figure 5*B*, to protect the cable. The protectors designed for location near terminal equipment usually consist of carbon blocks with a separation of three mils between blocks. Protectors used at the end of the cable are similar carbon blocks with about six-mil spacing. Use is also made occasionally for special purposes of a similar protector with ten-mil spacing.

The behavior of a protector of this type, particularly where the spacing is as close as three mils, depends upon a number of factors. Purely for illustrative purposes, figure 6 has been prepared from laboratory test data taken at 60 cycles. It shows the breakdown voltage distribution for a sample run of new three-mil blocks under certain specific conditions as to duration of test voltage and impedance of the test circuit. These factors, and also the number of operations to which the blocks have previously been subjected, affect the breakdown voltage characteristic as well as the ability of the protector blocks to withstand discharges without becoming short-circuited.

When induced voltages sufficiently high to break down the protectors are impressed upon the gaps on the two sides of the line to ground, there is a certain amount of dissymmetry in the resulting arc voltages across these two gaps. This sets up current through the receiver which may cause acoustic shock to the person using the receiver.

Voltages which might affect telephone linemen in the course of their work are voltages from wire to nearby grounded objects, and voltages between one wire

subject to induction and another wire grounded at nearby or distant points.

The reactions upon the subject of this paper of progress in the electrical communication art in the past decade are

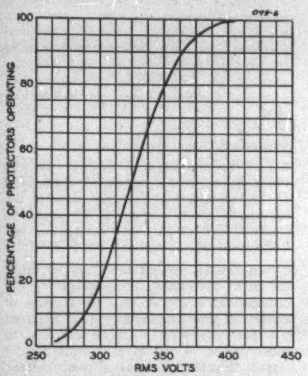


Figure 6. Breakdown characteristics of telephone open-space protectors—laboratory tests at 60 cycles

less direct than those of advances in the power industry, reviewed above. On the other hand, in the development of specific remedial devices for low-frequency induction situations, much has been done with regard to measures for use in communication systems. The effects of trends in the communication art and developments in communication system remedial measures will be discussed in succession.

New Telephone Carrier Systems

The principal developments in wire telephone and telegraph transmission during the past few years have been toward increased use of carrier circuits.

With the availability of a system which permits the use of wider frequency bands and correspondingly more carrier channels on open-wire lines,[45] some open-wire routes can be economically developed for larger numbers of circuits instead of being replaced by cable.

In existing toll cables, the application of carrier transmission makes increases possible in the number of channels per sheath,[46] which is bringing about a tendency toward smaller physical dimensions for new toll cables. This in turn means that the shielding against low-frequency longitudinal induction would tend to be diminished unless counteracted by deliberate increases in the sheath dimensions. Shielding effects exerted on each other by cables in close proximity, which depend essentially on the total conductance of all the sheaths, would be reduced by a reduction in either the size or the number of cables.

While these developments in carrier telephony, of which the coaxial cable[47] is the most recent, present new features, principally in connection with shielding, they do not change the nature of the technical problem in an essential way. An increase in the number of communication channels per physical pair of wires, and in the number of channels along a given route, of course emphasizes the desirability of protecting the system from disturbance. However, low-frequency induction, in this respect, does not stand on a different footing from other possible sources of disturbance, aside from limitations which may be encountered in the application of specific remedial measures, such as relay protectors, to the telephone line.

Signaling

Increasing use is being made of recently developed d-c signaling systems, composited or simplexed in a manner similar to superposed telegraph, for through supervision and dialing on both local and toll trunks. These systems are provided with terminal equipment for neutralizing longitudinally induced voltage or ground potential, the functioning of which requires that it be connected to a conductor exposed to the voltage to be neutralized. For this purpose, one wire of the pair, or in the case of a phantom group, one wire of the group, is used. This normally leaves one wire for each trunk for dialing or supervision. While this arrangement reduces the susceptiveness of the system, there have been some cases in which the neutralization was apparently insufficient to take care of low-frequency induction under normal operating power-circuit conditions. This matter is under investigation.

Induction from power-system voltages under normal operating conditions sufficient to disturb grounded party-line ringers has also been experienced in some cases of exposure to rural power circuits consisting of a single phase-wire and multigrounded neutral. A ringing system has been developed, and is in some use, employing cold-cathode gas-discharge tubes to keep the circuit free of ringing grounds except when the tubes are operated, as by ringing voltage. In its present form, however, this arrangement would frequently be ineffective against induction from rural-line exposures, of the type just mentioned, since the tube operating voltages must be held within magnitudes adapted to satisfactory operation of ringing systems.

Considerable work has recently been done and is continuing on the general question of the susceptiveness of telephone equipment, particularly equipment for signaling and supervisory purposes, to low-frequency induction.

Telephone Protectors

Development work is in progress in connection with the protectors used at stations and at junctions of open-wire and cable, particularly study of the possibilities of material having a nonlinear resistance-voltage characteristic. While some of these materials appear to be valuable for special purposes, the studies have not thus far resulted in any device that seems likely to replace the present protector for general application. As has been noted in a recent paper,[48] a 3,000-volt carbon electrode gap has been developed for use as a specific measure in cases of joint use at the higher voltages.

Relay Protectors

Relay protectors installed at terminals or at the junctions of open-wire lines and cables greatly reduce the probability of permanent protector grounding, and also minimize acoustic disturbance in the communication circuits. In addition, relay protectors installed along the line minimize the possibility of electric shock to linemen by reducing potential to ground throughout the entire line. The operation of relay protectors of course results in an interruption to the communication circuits for the duration of the disturbance.

The multigrounding type of relay protector operates so as to ground all wires of a telephone line at the point where the apparatus is installed when the voltage to ground at that point rises sufficiently to operate any one of the open-space protectors associated with the installation. The discharge of current through any one or more of the open-space protectors operates a master relay, which operates the relays associated with each protector. These individual relays each short-circuit the associated protector gap and prevent permanent grounding. The improvements over the earlier equipment[49] have been (*a*) substitution of an a-c master relay, in series with a saturating transformer, for the earlier combination of rectifier and d-c relay; (*b*) speeding up of operation, which is now completed in about 0.025 second; (*c*) increase in current-carrying capacity of the short-circuiting relay contacts; (*d*) increase in

minimum release current (master relay); (e) increase in capacity of master relay to absorb heat without damage. For relatively rare situations, in which the master relay may be held up by normal induction after the power-line fault causing its operation has cleared, means may be provided for opening all the short-circuiting relay contacts after a suitable interval, these contacts reclosing quickly if the fault condition should prove not to have cleared.

In addition to this "multigrounding" type of relay protector, a "unit type", applicable to a single pair of wires only, has been developed. It is used principally at points where protectors of the ordinary type would be subject to frequent grounding and where, because the location is remote, maintenance would be delayed or expensive.

Neutralizing Transformers

Neutralizing transformers installed along a communication line provide counter electromotive forces against induced longitudinal voltages, and permit the line to operate normally through inductive disturbances. A type of transformer for neutralization on voice-frequency toll circuits has been developed and has proved satisfactory in a service trial, where 12 were used in series in two inductive exposures totaling about 50 miles in length. Each transformer is wound with 24 secondary wires. The primary, consisting of two telephone wires, is grounded at each end of the exposure and between each two consecutive transformers. This trial installation proved satisfactory both in connection with neutralizing induced voltages and in meeting the circuit transmission requirements under normal operation. Additional installations have not been made as other means have offered more economical over-all solutions of specific cases. Further development work would be required to produce a transformer adequate for circuits over which carrier frequencies are transmitted.

A unit-type neutralizing transformer, to take care of a single circuit, has also been developed. This device consists of a single primary winding with two secondary wires. Where more than a single circuit is involved, a number of units can be used with the primaries in parallel. An important application of this device is in connection with maintaining uninterrupted communication service to power stations or substations, at times of power disturbances which cause large rises in the potentials of station grounds with respect to distant points.[50] Two sizes are in use, one for 4,000 and one for 2,000 volts (60 cycles). Frequently use can be made of a cable sheath for the primary or part of it. These transformers are now in operation in a number of places.

Acoustic Disturbances

The copper-oxide rectifying element[51] has superseded the earlier combination of step-up transformer and protector gap as a means of reducing acoustic disturbances to telephone operators. Tests and operating experience have shown that the copper-oxide element is about as effective as a reducer, and has no net effective transmission loss. It is smaller and lighter than the earlier type and the indications are that it will have a satisfactory service life in use at central offices.

In circuits with telephone repeaters, the nonlinear characteristics of the vacuum tubes cause the tubes to function as devices for limiting acoustic disturbances. A study of the quantitative relationships has been made, including determination of the factors to be taken into account in order to realize as fully as practicable the power-limiting possibilities.[52]

Conclusion

The foregoing review will have shown, it is believed, that the net result of development of the past ten years has been favorable to low-frequency inductive co-ordination. Over-all improvement has in fact occurred, and has accompanied a growth in the power and telephone industries which, though less than expected ten years ago, has not been inconsiderable. It is estimated that in the decade increases in the neighborhood of 30 per cent have taken place in power generating capacity and in mileage of transmission circuit in the range from 22 to 66 kv. In the Bell System, telephone toll circuit mileage has increased some 22 per cent and telephone stations about 7 per cent.

In an important degree, the contribution of the Joint D. & R. Subcommittee to this favorable result has been due to the assistance it has received from operating power and telephone companies. This helpful relationship will, it is hoped, continue in the working out of the problems that remain and the new ones to be expected from future growth and development.

Summary

We recapitulate here principal developments of the past decade in the problem of low-frequency induction, with remarks on the resulting present status and future plans for study of different phases of the problem.

General

1. Studies of effects in actual low-frequency inductive exposures have been useful in developing general procedural methods, but have indicated the need of further work on certain items, with reference particularly to facilitating the appraisal of proposed situations in advance of construction.

Influence

2. In the calculation of residual currents, the more important gaps have been filled by the experimental determinations of the impedance of ground-faults on operating systems, and of the impedances and admittances of lines (especially cables).

3. In residual-current limitation, probably the most interesting development is the installation, within the last three years, of about 30 Petersen coils. The Petersen coil generally limits residual currents to small values. Little or no change in the status of other methods of fault-current limitation has taken place. As heretofore, the application of fault-current limitation is primarily a matter of its reaction on power-system operation, although developments have somewhat simplified this question.

4. Frequency of occurrence of ground faults has been reduced by improvements in the insulation of power lines, including improved ground-wire application and features of structural design. In the reduction of duration of ground faults, the protector tube is probably the most important development from the standpoint of low-frequency induction. Others are increased speed of circuit-breaker operation, including high-speed relaying and closely simultaneous clearances at both ends of the faulted line section, and (except for permanent faults) the Petersen coil.

These developments have had a definitely favorable reaction on low-frequency inductive co-ordination, although it is impracticable to ascertain the extent of this, taking the country as a whole.

Coupling and Shielding

5. The theory of the mutual impedances of ground-return circuits has been extended to cover circuits of arbitrary lengths and contours, and now includes also certain types of heterogeneous earth structure. Some further work is desirable in simplifying the engineering application of the theory to types of problems which may be encountered.

6. Coupling tests should be made before final decision in important cases. Development work has cheapened and simplified field testing methods and apparatus, and is continuing.

7. Methods and data for calculating reductions in longitudinally induced voltages resulting from shielding currents in usual types of shielding structures have been published. In the case of telephone cables, the voltage between conductors and sheath

(as contrasted with longitudinally induced voltage) is of interest, and in long cables, shielding by currents in the conductors as well as by those in the sheath is important. These matters are currently receiving attention.

8. Shielding by currents in conductors which become grounded through protector operation is difficult to estimate, although it has frequently been found to be of considerable importance. Additional investigations of this factor are to be carried out.

Susceptiveness

9. Possibilities of using toll cables of relatively small physical dimensions, and of new structural designs, presented by developments in the application of carrier to cables, require consideration of changes in the inherent shielding afforded by the cable structure. These and allied questions may continue to require study for some time.

10. The use of composited d-c toll-line dialing and through-supervision systems is increasing. Inclusion in these systems of arrangements for neutralizing induced voltages reduces their susceptiveness to low-frequency induction, although further study of inductive co-ordination with these and other signaling systems is needed.

11. Development work on the relay protector has been substantially completed. This device has had a good record in use as a specific measure of co-ordination.

12. Two types of neutralizing transformers have been developed. One, for neutralizing ground potentials on communication lines serving power stations, is being successfully used in practice. The other, designed for toll-line use, proved satisfactory in field trial, but the probable field of use is small.

13. A copper-oxide device for reducing acoustic disturbances has been developed for use at operators' positions. Experience indicates that it is generally satisfactory.

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Discussion

L. F. Roehmann (Anaconda Wire and Cable Company, Hastings-on-Hudson, N. Y.): The authors gave an excellent review of the progress in the art of low-frequency inductive co-ordination which has been realized in this country during the past decade. It might be appropriate to add that during that interval substantial work has been done on the other side of the Atlantic also.

In 1926 and 1930, the CCIF issued "Guiding Principles Concerning the Means for Protecting Telephone Lines Against the Adverse Effects of High-Current or High-Voltage Lines." Last year, an entirely new edition has been published ("Guiding Principles Concerning the Protection of Telecommunication Lines Against the Adverse Effects of Industrial Power Lines"). This publication, containing 150-odd pages, is an up-to-date textbook on inductive co-ordination rather than just a set of recommendations. It climaxes the co-operative efforts of the International Mixed Commission for the Study of Inductive Interference, the CCIF, and a number of other international groups and organizations. Power and communication engineers of France, England, Germany, Switzerland, Sweden, and many other countries contributed to its setting-up.

The publication is written in French but an English translation has been prepared. While many of the minor details are different in the two hemispheres, the basic conceptions are of course the same.

J. W. Milnor (The Western Union Telegraph Company, New York, N. Y.): This paper discloses a very healthy condition in the development of low-frequency inductive co-ordination. A comparison with that presented in 1931 by Messrs. Conwell and Warren makes it evident that the past ten years have produced few actual changes in the basic method of attack; instead there has been a continuous advance in the knowledge of the problem, of the mathematics which represents the variable conditions, and of the apparatus and equipment necessary to provide the desired safety and stability of service.

The scope of the discussion is so broad that within the necessary space limitations the authors have been able to describe only the most prominent advances. Fortunately there is included a bibliography which in itself is an index of the extent of the progress, and which should be of much value to the reader who desires more intimate knowledge of any phase of the problem.

The authors have dealt chiefly with the transient low-frequency interference which occurs particularly at times of fault conditions in the power system. They have perhaps underemphasized the continuous interference which may occur during normal power operation, and which often has serious effects especially to high-speed telegraph circuits, although it is rarely damaging to the telephone.

J. O'R. Coleman: Mr. Trueblood and I greatly appreciate L. J. Roehmann's remarks regarding the report of the Comite Consultatif International Telephonique. The English edition of the report of the 11th Plenary Meeting held in Copenhagen, was published in 1938 by the International Standard Electric Corporation, and contains considerable interesting information. Due to the many different conditions existing in European practice, technical, economic, and social, we do not feel that in general the work of the CCIF can be directly applied to American practice, although many of the technical findings are useful.

A Precision Rotating Standard for the Measurement of Kilowatt-Hours

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THE accuracy with which electrical energy is metered is dependent upon the apparent measured value of the kilowatt-hour used. Quite independent of the electrical operating characteristics of the watt-hour meters used or the accuracy limits within which they are adjusted, the average accuracy of a group of watt-hour meters is directly affected by the difference between the value of the kilowatt-hour used and the true value.

The apparatus used to derive the unit while satisfactory for reference does not lend itself to practical use in the checking and calibrating of watt-hour meters in commercial installations. Specially designed and compensated induction-type watt-hour meters, which are calibrated in the laboratory approximately as outlined in table I, have long been used as commercial working standards. These watt-hour meters are known as portable standard watt-hour meters and have been developed to a high degree. In fact, so well do they perform that an improvement in the method of standardizing them is justified.

It is the purpose of this paper to describe an improved system for maintaining the value of the kilowatt-hour to be used primarily for the calibrating and checking of portable standard watt-hour meters.

Analysis of Errors in Method of Checking Rotating Standards

Table I shows the limits of probable error present in the various steps of a particular system. It is evident that all of the values given in table I could add up to be (+) or could add up to be (−) if a sufficiently large number of checks were taken. The probability of either of these two conditions occurring is much less than is the probability of some steps compensating others due to differences in the sign of the errors. Should all errors add (+) the result would be

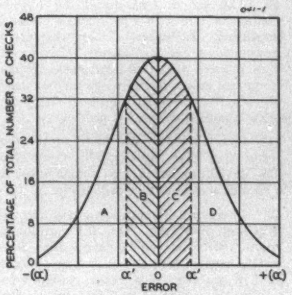


Figure 1. Absolute error in per cent

a +0.245 per cent variation, and if all (−), a −0.245 per cent error. It is important, therefore, to obtain some idea of the most likely way the error of the various steps will combine to determine what over-all accuracy is to be expected.

Paper 40-41, recommended by the AIEE committee on instruments and measurements, and presented at the AIEE winter convention, New York, N. Y., January 22–26, 1940. Manuscript submitted November 13, 1939; made available for preprinting January 3, 1940; released for final publication March 5, 1940.

J. H. Goss is engineer in charge, works laboratory, and A. HANSEN, JR., is engineer, General Electric Company, Lynn, Mass.

Consider a theoretical distribution curve, figure 1, and for the purpose of illustration let the abscissa represent a system of errors similar to table I. To avoid confusion the error limits have been designated $\pm\alpha$. If a large number of checks are made, figure 1 will represent a plot of the results. The tests showing zero error will be the most frequent, but the extreme errors will occur in a small percentage of the readings when the component errors have the same sign.

The technician must realize that with a small number of readings the average value may not be a fair one. If it should occur that in five readings a high (+) error is obtained with four smaller (+) errors, the average would be (+) and would depart appreciably from the absolute value. It is important that a sufficiently large number of readings be taken to show up the individual readings with large variations from the mean.

As the total area under the curve, figure 1, represents all of the readings, half of the area will represent half the total number of readings. The areas A, B, C, and D have been divided to make each equal to one-fourth the total area $(B+C=A+D)$.

The abscissa of B is $-\alpha'$ and of C is $+\alpha'$. The combined areas $B+C$ represent half the total number of readings, and it is, therefore, reasonable to state that one-half of the readings taken are probably within the area $B+C$ and are therefore, within $\pm\alpha'$. This value of the abscissa ($\pm\alpha'$) will be referred to as the probable error.

Precision Rotating Standards Method

The schematic diagram shown in figure 2 gives the circuit and essential elements of a system of three precision rotating standards. This system is capable of maintaining a high degree of accuracy. It will first be described in its component parts and then its method of operation, together with actual performance data, will be given.

A. Rotating Standards

The rotating standards shown in figure 3 are used as the measuring elements. These were made by taking a commercial portable standard watt-hour meter, removing the register, and rewinding the current coils for a five-ampere current rating only.

The standards were removed from their cases and mounted as shown in figure 4 in a walnut case. Incandescent-lamp housings and lens systems were mounted above the meters and photoelectric cells in suitable housings were mounted below the case. Glass windows were provided in the top and bottom of the case to allow the light from the light sources to be focused through a small hole in the meter disk onto the photoelectric cell below. The case was completely sealed against dust and mounted on a vibration-free concrete wall in a (22 degrees centigrade) controlled-temperature room. Each rotating standard was carefully compensated for both unity and 0.5 power-factor lagging temperature errors (class I and class II errors).[2]

Each rotating standard, together with its light source and photoelectric cell, is considered as a unit having no functional relation with the other two. For the purpose of identification these will be called precision rotating standards numbers 1, 2, and 3.

B. Transformers

The standards were designed for 120 volts and five amperes, but a high-

Table I

Step	Fundamental Measuring Circuit and Type of Measurement	Source of Error	Limit of Error
A—Potentiometric method of maintaining voltage and current from a standard cell using a voltage multiplier and shunt	Figure *A*—Potentiometric method of maintaining a voltage Figure *B*—Voltage multiplier method of maintaining a standardized test voltage Figure *C*—Shunt method of maintaining a standardized test current	1—Error in the standard cell	±0.01
		2—Error in balancing cell	±0.01
		3—Error in resistance arms	±0.01
		4—Error in multiplier	±0.01
		Total maximum error for sources 1, 2, 3, 4	±0.04
		5—Error in shunt	±0.01
		Total maximum error for sources 1, 2, 3, 5	±0.04
		Total maximum error	±0.80
B—Calibration of dynamometer wattmeter on direct current	Figure *D*—Potentiometric method of calibrating a dynamometer wattmeter on direct current	1—Holding deflection of wattmeter at scale point	±0.02
		2—Holding voltage	±0.01
		3—Error in voltage value step *A*	±0.04
		4—Error in current value step *A*	±0.04
		Total maximum error	±0.11
C—Calibration of induction-type watt-hour meter	Figure *E*—D-c to a-c dynamometer wattmeter transfer Figure *F*—Time element of power equation $W = \frac{Kh \times N \times 3{,}600}{t}$ W = meter watts Kh = meter disk constant N = revolutions t = time (seconds)	1—Holding wattmeter setting (load varying)	±0.04
		2—Error in checking wattmeter step *B*	±0.11
		3—Change in wattmeter calibration from check value	±0.03
		4—Punching key (human error)	±0.05
		5—Error in measuring chronograph sheet	±0.01
		6—Error in timing mechanism	±0.005
		Total maximum error	±0.245

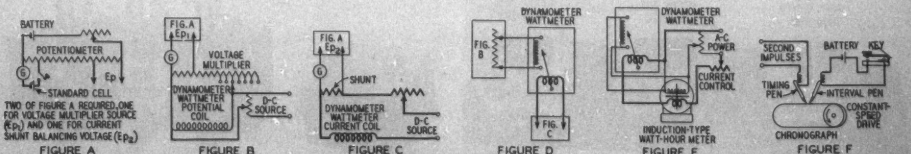
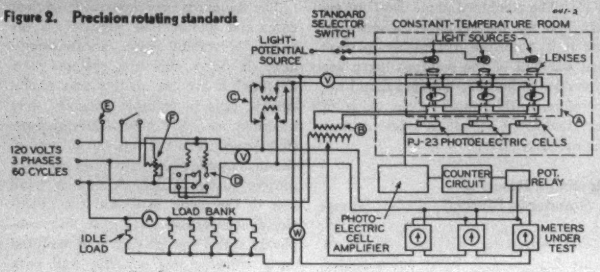


Figure 2. Precision rotating standards



accuracy current transformer having a Mumetal core is used to allow the standards to operate at five amperes under all test conditions. The ratios available are shown under *B* in figure 2 and allow for all points required for the commercial checking of portable rotating standards. The current transformer has a ratio error within 0.04 per cent on all coils and a phase angle error within one minute on all coils.

A potential transformer is provided for 240-volt operation.

Not only are the transformers designed for low inherent errors, but they are considered as an integral part of the precision rotating standard circuits and all calibrations made in accordance with table I are made on the combination. This method of calibration was employed using instruments for all current ratings to check the meter and transformer combination. Although the ratio and phase-angle errors were determined for the transformers, they were not used in arriving at the calibration of the standards.

C. Photoelectric-Cell Testing Relay Circuit and Auxiliary Switching

A photoelectric-cell amplifier, figure 2, is provided which operates a counter circuit which can be preset to energize through the potential relay the potential circuit of one or more portable standard watt-hour meters and to keep the potential circuit or circuits energized for the preset number of revolutions of the precision rotating standard.

A—Three special *1B* standards mounted in dust-tight case, special 0.060-inch hole in disks for light shutter

B—Current transformers, ratios 1:0.2, 0.25, 1, 2, 2.5, 10; tap chosen by jumper

C—Potential transformer, 2:1, connected by jumpers

D—Potential transformer, 1:2, connected by 100-ampere switch (for low contact resistance)

E—100-ampere switch for phase selection

F—Voltage regulator

By means of a suitable switch, precision rotating standard number 1, number 2, or number 3 may be used to control the portable standard watt-hour meters under test. The repeatability of the relays and photoelectric circuit is in the order of ±0.01 per cent for ten revolutions. The precision rotating standard being used runs at the selected load continuously and only the standard under test is started and stopped.

Method of Use and Results

Each of the three precision rotating standards is operated continuously when not being used for test work at two per cent of rated current and with rated potential applied. This eliminates any error due to potential-coil heating.

The error in the calibration of each of the precision rotating standards is determined by repeated checks in accordance with the steps shown in table I. At no time since the beginning has any change been made in the adjustments of any of the three standards. It is then desirable to cross-check the precision rotating standards in terms of one another using a portable standard watt-hour meter as the transfer medium. If the standard used for the transfer has a known history of calibration, it is valuable as a reference to show up any major changes in absolute values of any of the precision rotating standards.

It would be desirable not to introduce the fourth standard for the purpose of intercomparison. It is possible to use one of the three precision rotating standards for this purpose, and this will eventually be done. The results of using a transfer have been quite satisfactory to date.

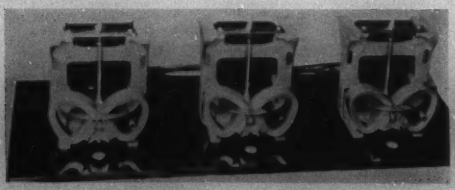
Figure 5 shows the results of such an intercomparison over a period of five months for the five-ampere 120-volt load point operating at unity power factor. Precision rotating standard number 1 is assumed to be correct and number 2 and number 3 are plotted in terms of their deviation from number 1.

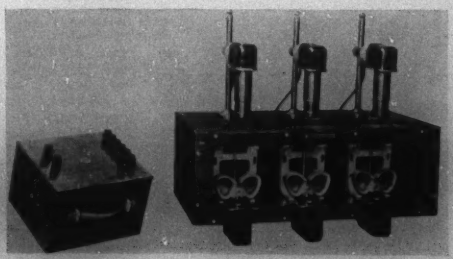
The maximum variation in number 2 from the original reading is +0.06 per cent and of number 3, −0.06 per cent over the five months' period. Note that at the end of the period number 2 is +0.03 per cent above the original reading and number 3 is −0.01 per cent below its original reading.

Figure 6 shows the same intercomparison as figure 5 except that the load point used was 120 volts, five amperes, and power factor 0.5 lagging. It is to be expected that a greater variation will be obtained using this load due to other variables operating. For example, variation in phase angle, wave form, frequency, and temperature are more effective in

Figure 4. Precision rotating standards complete with light sources, photoelectric tubes, and precision current transformer adjacent

Figure 3. Precision rotating standards without case





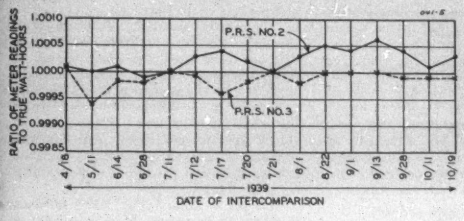


Figure 5. Intercomparison data on precision rotating standards corrected in terms of standard number 1

Five amperes, 120 volts, 60 cycles, unity power factor

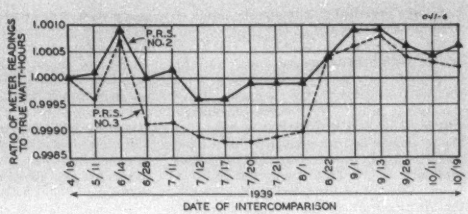


Figure 6. Intercomparison data on precision rotating standards corrected in terms of standard number 1

Five amperes, 120 volts, 60 cycles, 0.5 power factor lagging

producing calibration change than at unity power factor. The maximum variation of precision rotating standard number 2 is +0.09 per cent and of precision rotating standard number 3, −0.12 per cent. At the end of the period, number 2 is +0.06 per cent above the original reading and number 3 is +0.02 per cent above the original reading. No change in the adjustments were made at any time after the initial readings were taken.

Figure 7 shows the results of 36 separate checks made over the five months' period in accordance with table I. The most probable error in absolute calibration is ±0.04 per cent from the mean. The initial instrument check was assumed to be correct for the purpose of plotting the data in figure 7. It is evident that the initial point was low by −0.06 per cent and a better value of the absolute calibration is the peak ordinate or +0.06 per cent above the initial reading. The distribution curve was drawn by first determining the mean and standard deviation for the results of the 36 checks and calculating the ideal curve to fit the data.

Certainly, these standards are running together within far closer limits than any single instrument check can be relied upon to reveal. This is, however, the ideal condition for obtaining the true mean value in accordance with table I. If the precision rotating standards remain constant and the interchecks reveal that they are, then their calibration will approach the value of the maximum ordinate in figure 7. As all these standards were intercompared, figure 7 represents the instrument check on each of the standards.

Should some factor influence all of the standards to drift at exactly the same rate, the intercheck would not reveal the drift. As continual periodic instrument checks are obtained, curves similar to figure 7 can be plotted and compared one with another to show up this drift.

The actual use of this method for checking portable standard watt-hour meters is evident. Each precision rotating standard has a definitely established calibration so that one revolution of the disk under a given load corresponds to a definite kilowatt-hour value. By placing the portable standard watt-hour meters to be checked as shown in figure 2, any one of the three precision rotating standards may be selected to deliver a given number of kilowatt-hours to them. The ratio of the reading of the individual portable standard to the known value of the precision rotating standard is a measure of its accuracy.

The average of the calibration obtained using each of the three precision standards in turn to control the portable standard watt-hour meter or meters under test will give the highest precision. In practice, however, the additional accuracy is not justified because of the additional time required.

The high accuracy of the photoelectric testing system makes it necessary to take runs of no longer than 60 seconds for any given point. This greatly speeds up the calibration check of the portable standard watt-hour meters.

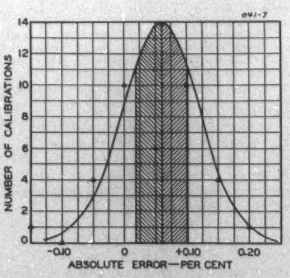


Figure 7. Curve of distribution of absolute error for repeated checks of precision rotating standards

Five amperes, 120 volts, 60 cycles, unity power factor

Conclusions

1. It has been demonstrated that for the highest accuracy of calibration of portable standard watt-hour meters using instruments, a number of readings must be taken and properly weighted.

2. A new system of precision rotating standards has been described that has high inherent accuracy together with fast operation.

3. With care it is entirely practical by the system described to insure the absolute accuracy of the kilowatt-hour used in checking standards to within 0.06 per cent at unity power factor loads and 0.12 per cent at 0.5-power-factor lagging loads.

References

1. Temperature Errors in Induction Watt-Hour Meters, I. F. Kinnard and H. T. Faus. AIEE Transactions, February 1925, pages 275–87.

2. International Standard of Electrical Force and Its Low Temperature Coefficient Form, Marion Eppley. AIEE Journal, May 1932, pages 341–3.

3. Development of a Modern Watt-Hour Meter, I. F. Kinnard and H. E. Trekell. Electrical Engineering (AIEE Transactions), January 1937.

4. Method of Least Squares (a book), D. P. Bartlett. Third edition, published by the Harvard Co-operative Society, Cambridge, Mass., 1915.

Discussion

George B. Schleicher (Philadelphia Electric Company, Philadelphia, Pa.): The authors are to be congratulated upon their contribution to the important field of maintaining the accuracy of laboratory-standard watt-hour meters. The elimination of "start-and-stop" errors in the so-called master standard, by causing it to rotate continuously during the calibration, serves also to eliminate such errors from the working standards when their corrections are determined by tests *over the same intervals that are used in service.*

From a practical standpoint the limits of accuracy as covered in table I appear rather small. For example, holding a wattmeter setting within 4/100 per cent with varying load (table I, step *C*-1) would be a very difficult problem in the average utility laboratory where the source of energy supply is from a distribution system. In the calibration of standard watt-hour meters with wattmeters, manual control to maintain a constant load introduces a human element of error, and there is a need for an *automatic* means of obtaining *constant wattage* independent of voltage variation. We have succeeded in accomplishing this, at least experimentally, by electronic means.

In the standard described by the authors, bearing friction is reduced by operating the standard only at full-load speeds, but possibly further improvements can be made in this direction. While the magnetic suspension is not new, modern magnetic materials, as for example Alnico, have made possible the design and construction of practical meter bearings of this type. This construction may prove highly desirable for

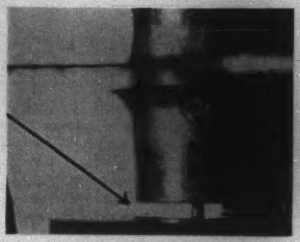


Figure 1. Enlarged view of magnetic suspension on watt-hour meter

The arrow points to the air gap which represents the bearing surfaces

service meters. Figure 1 of this discussion shows such a bearing developed by Walter C. Wagner of the Philadelphia Electric Company, and constructed of magnet materials contributed at our request by the General Electric Company. In the figure the air gap indicated by the arrow shows a greatly enlarged view of the bearing. Meter-performance tests over extended periods show consistent results superior to those of pivot and jewel bearing construction particularly at light load, thus permitting accurate performance to be maintained in standards and meters at lower operating speeds than with the conventional types of bearings. This type of suspension would undoubtedly further improve the uniformity of performance of the precision standards described by the authors.

W. J. Seeley (Duke University, Durham, N. C.): I should like to ask a question which is old but the philosophy of which is quite intriguing. It may have been answered to the satisfaction of manufacturers long ago, but not enough information has been given in print to put at rest a question which comes up with fair regularity. It is conceivable that by proper construction and adjustment the greater part of the weight of the rotor on the lower jewel may be removed by magnetic attraction, thus considerably reducing the friction loss. The question then is this: In an effort to reduce the rotation losses of your precision rotating standard, had you considered the possibility of reducing the weight of the rotor on the jewel by the use of a permanent magnet suspended just above the upper end of the shaft?

Wm. M. Young (Ohio University, Athens): Of particular interest in this paper is table I giving assigned values to the various sources of error encountered in standardizing and calibrating rotating standard watt-hour meters. It is assumed that all measurements were made using sinusoidal waves of current and voltage and that the authors were not concerned with irregular wave forms.

The question naturally arises as to whether or not the errors in the instrument check are inherent and whether they cannot be minimized by any standardizing laboratory if the equipment is properly aged and maintained at a constant temperature and if repeated trials are made and the results plotted on a probability curve. Naturally any laboratory can, in this way, reduce the 0.11 per cent accumulated error in the wattmeter's calibration by using proper care.

Might I ask the authors about the 0.03 per cent error assigned in *C*-3 "change in wattmeter from check value". Are there any data available on the accuracy of the determination of this error? Naturally it can be partially reduced if the time interval between checking the meter and using the meter for a watt-hour meter calibration is reduced to a minimum.

It would seem that the greatest contribution of this paper lies in the substitution of

1. A machine-switching machine for a hand-switching machine. This naturally affects the magnitude of errors *C*-4, *C*-5, and *C*-6. They total, as indicated by the table, 0.065 per cent.
2. Multiple standards cross-checked against each other in place of human observation for *C*-1.

In figure 5 might I ask about the drift of the readings in rotating standards with time? It would seem that an aging effect might be here showing up and that the meters would eventually tend to stabilize at some constant error.

In figure 7 might I ask why the point at 0.05 per cent error was not used in the determination of the probability curve? It would seem that more data should be taken before a good probability curve can be drawn and that results should not rely on merely 36 readings.

A. E. Vivell (Princeton University, Princeton, N. J.): It is gratifying to see that the actual title of this paper describes the meter as a "precision" meter and not as a "primary" standard as announced in the advance notices. It would be unfortunate to handicap such an excellent and interesting development with a misnomer.

The calibration procedure described is most thorough and provides a very comforting check on the constancy of these meters. However, the figures in table I seem to show a probable error of about 0.08 per cent in the watt-hour used in checking the rotating standard. It would seem, therefore, that the probable variation of 0.04 per cent from the mean shown in figure 7 is somewhat low. An exceedingly slight change in only four of the calibration points (at 0 and +0.10 per cent) could make the curve much flatter. If the point at +0.05 per cent were taken into account the probable error would be increased to about 0.08 per cent and the theory of probability restored to favor.

This paper again brings home the fact that the measurement of a watt-hour is handicapped by the lack of a simple scheme of measurement. When the meter error becomes less than the error of the standard it is time to work for better standards. It would be interesting to know if the authors have considered trying to improve their watt-hour by means of some other scheme of calibration; for example, a calorimeter or some other energy device.

A. Hansen, Jr.: An analysis of the discussions of our paper reveals four general points of comment: first, the limits of errors shown in table I; second, the manner in which our data were handled and the derivation of the probability curve shown in figure 7; third, bearing considerations; and fourth, the apparent better accuracy of the watt-hour meter than the calibrating standards.

The values shown in table I represent the results obtainable with extremely careful control of each step starting with the standard voltaic cell. Special sources of power of as constant regulation as possible are used without the use of electronic regulators. The authors feel that the values shown are representative for the method, and are the result of a number of years of experience.

An automatic device for holding load might be applied to some advantage in the system described. Up to the present time, however, the authors have had no experience with such a device.

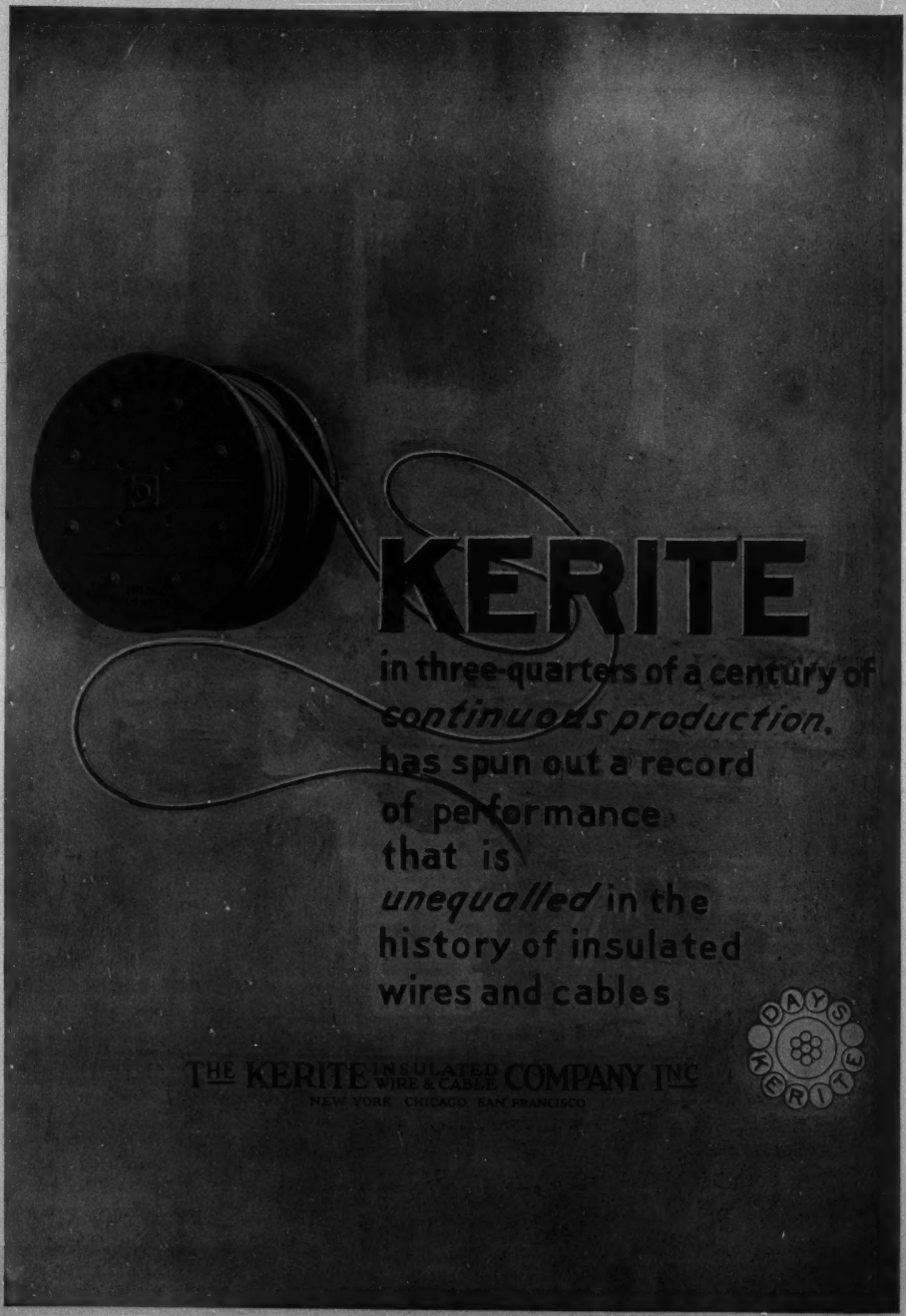
The authors recognize the fact that insufficient data were obtained to fix positively error magnitudes. It was the purpose of the paper to describe a method and a system of arriving at a precise value of the watt-hour.

The probability curve in figure 7 was plotted considering all calibration values and is not sketched in from the grouped data plotted but was calculated from the actual data.

Inasmuch as the precision rotating standards rotate continuously at full-load speed for all check points, the variations due to bearing friction are practically negligible. A magnetic-suspension type bearing is an interesting device in view of the new magnetic materials available.

At the present time no practical way of obtaining the value of the watt-hour is known to the authors that is basically different from the method outlined in table I. Energy-equivalent methods have been experimented with such as the calorimeter. The difficulty in using the calorimeter is not with measuring the heat values, but in determining the correction for heat loss.

In conclusion, the authors wish to express their appreciation for the very excellent criticisms they have received and hope that all questions have been satisfactorily answered.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Industrial Notes

Westinghouse Marine Orders.—New construction work on 114 marine turbines at a cost of $13,000,000, to provide power for 34 navy ships, oil tankers and merchant cargo vessels, is under way at the South Philadelphia steam turbine plant of the Westinghouse Electric & Mfg. Co. The marine turbines now under construction will produce a total of 1,211,000 horsepower and will include power equipment for the 45,000-ton U.S.S. New Jersey, world's largest battleship, now being built at the Philadelphia Navy Yard and two other battleships, as well as four cruisers and six destroyers. Some of the tankers now under construction for American oil companies will be the highest-powered, fastest, single-screw oil tankers afloat. Two being built by the Sun Shipbuilding Co., for the Texas Oil Co., will have 9000 horsepower each and four being built by the Bethlehem Steel Co. for the Socony Vacuum Oil Co., will have 12,000 horsepower each. Each of the tankers will be equipped with two Westinghouse turbines.

Copperweld Steel Appointments.—Paul Lindberg, formerly superintendent of rolling mills of the steel and tube division of the Timken Roller Bearing Co. has been appointed superintendent of rolling mills of the new plant of the Copperweld Steel Co., at Warren, Ohio, and W. J. Buechling is now chief metallurgist. Mr. Buechling was previously connected with the Central Alloy and Republic Steel corporations.

Turbine Contracts to Allis-Chalmers.—Orders for two complete hydroelectric units to be built for the Wilson Dam project of the Tennessee Valley Authority have been received by the Allis-Chalmers Mfg. Co. Each will be rated at 35,000 horsepower, to operate at a speed of 100 rpm under 92-foot head, with two governor systems and two 28,000-kva water wheel generators. The company has also received an order for the third hydraulic turbine and governor for the Pickwick Landing Station of the TVA. The new unit will again be rated 48,000 horsepower at 81.8 rpm under 43-foot head and will have the same physical dimensions as the first two turbines for which Allis-Chalmers received the award in 1936.

Trade Literature

Meter Testing Tool Kit.—Bulletin 15. Describes a tool kit consisting of 20 items, with canvas roll, for meter and relay testers. The States Co., 19 New Park Ave., Hartford, Conn.

Instruments.—Bulletin MI, 8 pp. Describes square and round ammeters, voltmeters, milliammeters,—switchboard and panel types. Burton-Rogers Co., 857 Boylston St., Boston, Mass.

Cable Research.—Brochure, 32 pp. An elaborate photographic treatment of numerous phases of research work and testing facilities in the laboratories of a large insulated wire and cable manufacturer. The Okonite Co., Passaic, N. J.

Speed Measuring Instruments.—Bulletin 1650, 4 pp. Describes and illustrates mechanical and chronometric hand tachometers, speed indicators, tachoscopes, etc.; also Frahm vibrating-reed tachometers, frequency meters and vibration-per-minute indicators. James G. Biddle Co., 1211 Arch St., Philadelphia, Pa.

Power Cables.—Cat. 6120, 40 pp. Describes various types of paper insulated power cable. Contains numerous tables, engineering data; includes specifications and standard practices, and outlines the processes of applying insulation, shielding, impregnation, etc. American Steel & Wire Co., Rockefeller Bldg., Cleveland, Ohio.

Clip-On Ammeter.—Bulletin, 4 pp. Describes portable, multiple-range clip-on ammeters used for accurate current readings, by simply encircling the live conductor (up to $2^1/_4$ inches square) with the rectangular jaws of the device. Ranges from 0-10/25/100/250/1000 amperes. Ferranti Electric, Inc., 30 Rockefeller Plaza, New York, N. Y.

Insulated Clevises.—Bulletin 688-H. Describes three sizes of spools, including one for standard secondary rack use, and four types of insulated clevis assemblies using these spools. Drawings show typical applications of both spools and assemblies. Ohio Brass Co., Mansfield, Ohio.

Motors.—Bulletin, 8 pp. Illustrates and describes the design and operation of capacitor start, type F, single-phase motors. Mechanical and electrical characteristics are fully covered; includes diagrams and charts. U. S. Electrical Motors, Inc., 200 E. Slauson Ave., Los Angeles, Calif.

Ball Bearings.—Catalog 35X, 130 pp. Contains complete data on dimensions, load ratings, types and sizes of Fafnir bearings, covering a complete line of radial, thrust, precision, self-aligning and sealed bearings and housed transmission units. More than 55 distinct types, embracing over 100 series, are covered. The Fafnir Bearing Co., New Britain, Conn.

Oil Circuit Breakers.—Bulletin DD33-555, 8 pp. Describes indoor oil circuit breakers with interrupting capacities of 75,000-kva, and designed especially for use in generating stations and industrial plants where minimum space is available. Manually or electrically operated; available in ratings of 600, 1200, and 2000 amperes at voltages of 15,000, 7,500, and 5,000 volts respectively. Westinghouse Electric & Mfg. Co., East Pittsburgh, Penna.

Transformers.—Bulletin GEA-2442C, 16 pp. Describes type HBA distribution transformers. Features include exclusive wound core ("Spirakore") construction in $1^1/_2$, 3 and 5 kva sizes; overcurrent protection is provided by a low voltage circuit breaker; heavy duty pellet-type lightning arresters are mounted directly on the tank. These transformers are available in one- and two-high-voltage-bushing design. General Electric Co., Schenectady, N. Y.

Insulating Materials.—Bound data sheets, 12 pp., "Lumarith Protectoid, Its Characteristics and Applications for the Electrical Industry". A detailed, comprehensive description of a cellulose-acetate film, the electrical and physical properties of which make it applicable as turn insulation on fine wires as well as power cables; and as core, coil and slot insulation; dielectric for condensers; laminated to paper, cloth and mica tape; and other purposes. Celluloid Corp., 180 Madison Ave., New York, N. Y.

Farm Wiring.—Handbook, 28 pp. A guide for planning electrical wiring on farms. Particular attention is given to planning the feeders between the service entrance and the different buildings, and to the feeders within the buildings themselves. Ways for determining feeder sizes are given and methods for installation recommended; suggestions are also given for the number of outlets needed and their location. Helpful charts and tables are included. One chapter of the handbook is devoted to the various elements to be incorporated in specifications, and should be helpful both in preparing specifications and in checking those written by others. General Electric Co., Bridgeport, Conn.

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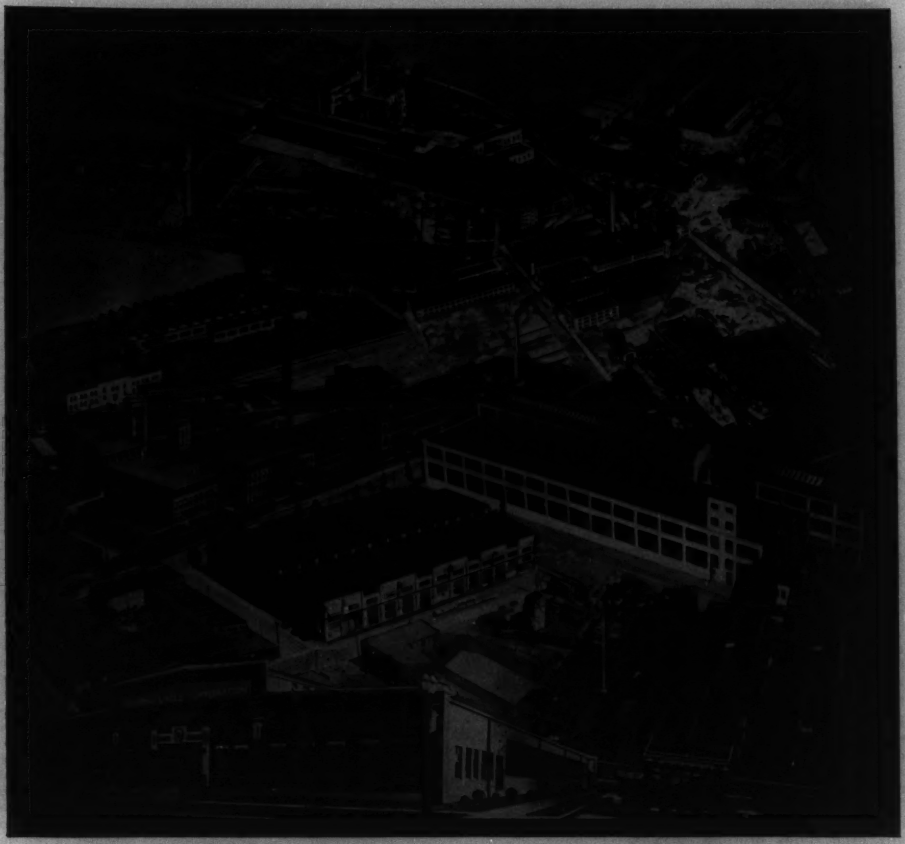

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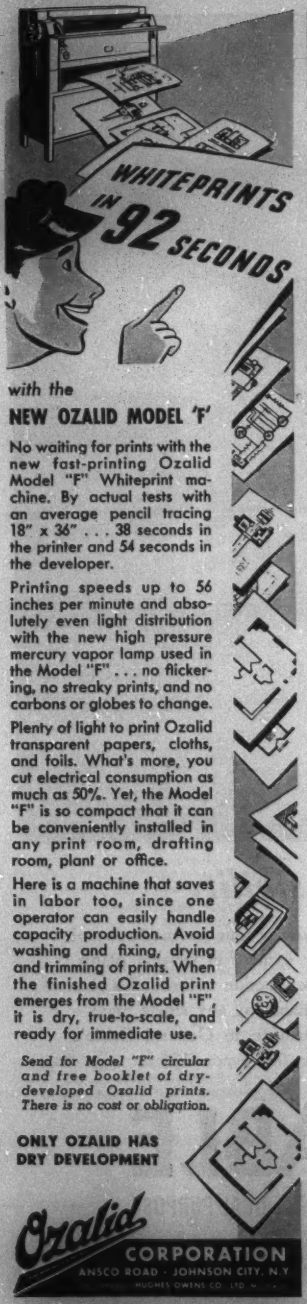

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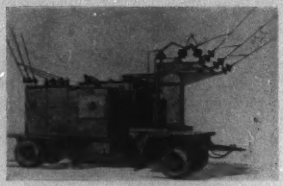

supplying service quickly at any point on their distribution circuits where emergency service is required or where temporary loads demand increased capacity. To give the desired balance between size, weight, and output, two general types are available—one using a self-cooled transformer and the other a forced-cooled transformer. The self-cooled type is especially suited for the smaller sizes and, as it requires no attention, is ideal for duty that may include extended periods of continuous service. The forced-cooled type is a compact, high capacity unit which provides minimum weight and size for a given rating, and thus is well suited for rapid emergency service. Installation of the new unit is merely a matter of parking and grounding the unit in a convenient location, elevating the retractable high-voltage disconnecting-switch structure, and running conductors to the high-voltage and low-voltage lines. All the features of G-E permanent substation installations may be incorporated in the portable unit. When in service the maximum dimensions of a 1,500-kva unit of the larger continuous-service type are approximately 22 feet long, 8 feet wide, and 15 feet high, and the maximum weight is 37,500 pounds, including trailer. Units of the emergency-service type are very compact; for example, one rated 2,000 kva will weigh only about 20,000 pounds.

Dead-End Strain Carrier.—This new strain carrier device has been designed for removing and replacing defective insulators up to 10 inches, on power line deadends. Developed by the A. B. Chance Co., Centralia, Mo., it has a built-in ratchet wrench for use

in taking up slack on strain insulators. The point on the arm at the right of the picture digs into the back of poles or crossarms and the socket arrangement at the left fits over the insulator clevis, and by operating the ratchet wrench handle the slack may be taken up to enable the operator to disconnect insulator strings and replace them without interrupting service. An eye screw on the bracket at left makes it possible to lift the strain carrier into place by use of an ordinary disconnect stick or similar hot line tool. The entire unit is light weight, easily operated, and makes possible quick insulator changing. The hard wood board provides the necessary insulation for safety for the operator.

Lightning Arresters.—A new line of type "LV" unit design lightning arresters, covering the range from 20 kv to 73 kv, and designed primarily for the small substation where reliable protection at low cost is desired, is announced by the Westinghouse Electric & Mfg. Co. Complete arrester units 20, 25, 30, and 37 kv consist of three-inch diameter, porous block elements, and a multiple series gap of resistance type spacers, and metal electrodes. Entire assembly is encased in wet process porcelain, hermetically sealed. Following unit design practice, units above 37 kv consist of combinations of two single units, for instance, a 40-kv arrester would consist of two 20-kv units, etc. The two units combine to form one integral arrester. Features include absolute moisture proofing brought about by the solder hermetical seal at each end casting. Greatest improvement is in protective

ability against lightning, every arrester being guaranteed to discharge at least 65,000 surge amperes on a 5–10 micro-second wave. This is possible because of the three-inch diameter resistance blocks, formerly used only on arresters rated 50 kv and above. Gap breakdown is uniform and stabilized by the resistance type spacers and metal electrodes. To insure their handling "long-tail wave" lightning, and freedom from radio interference, each arrester is tested in the laboratory under rated power voltage. Self-supporting, they may be mounted directly on transformers, or other equipment.

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Amerclad owes its amazing toughness to a special rubber formula developed by years of research in the laboratories of the American Steel & Wire Company. Nothing but the finest Hevea rubber is used in its compounding. Its minimum tensile strength is 3500 lbs. per sq. in. Samples are required to stretch six times their own length before breaking. All Amerclad cables are vulcanized under enormous pressure, while encased in a heavy lead sheath that is afterward removed. This treatment bonds the rubber fillers and the jacket inseparably together to prevent tearing or stripping of the protective sheath.

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IN THE MINES · ON ELECTRIC SHOVELS · FOR ELECTRIC TOOLS · FOR WELDING

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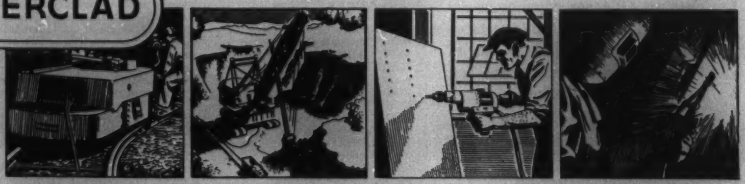

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☐ 39-116	Harrison	Ionization Time of Thyratrons
☐ 39-120	St. Clair*	Multiwinding Transformers with Synchronous Condensers
☐ 39-121	Marti & Taylor*	Wave Shape of 30- and 60-Phase Rectifier Groups
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☐ 39-127	Benson & Strang	12-Kv Metal-Enclosed Bus and Switch Structure
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☐ 39-134	Maiti & Herzog	Fractional-Slot and Dead-Coil Windings
☐ 39-136	Dickerson & Mahan	Painting the Golden Gate International Exposition With Light
☐ 39-137	Kilitie*	New Type of D-C to A-C Vibrator Inverter
☐ 39-138	Davis*	Signal System, San Francisco-Oakland Bay Bridge Railway
☐ 39-139	Hanna & Tritle	Electrical Equipment of the Steam-Electric Locomotive
☐ 39-140	Reinitz & Wiseman*	A New Technique for Lead Cable Sheathing
☐ 39-141	Smith & Tenney	Temperature Survey of the United States
☐ 39-144	Aggers, Foster & Young*	Instruments and Methods of Measuring Radio Noise

Minneapolis Meeting

☐ 39-147	LeClair*	Arc-Furnace Loads on Long Transmission Lines
☐ 39-148	Summers*	An Unstable Nonlinear Circuit
☐ 39-149	Foust & Rohats*	Developments in Impulse-Voltage Testing
☐ 39-150	Peterson, Rudge, Monteith & Ludwig*	Protector Tubes for Power Systems
☐ 39-151	Fountain, Dissmeyer & Elsi	Co-ordination of Control of Synchronous-Machine Excitation
☐ 39-152	Maxfield, Hegbar & Eaton	Importance of Gas in Electrodes for Glow-to-Arc Transition
☐ 39-153	Swanson	Polarized Field Frequency Control of Synchronous Motors
☐ 39-154	Smith & Bostwick	Ratio Differential Protection of Transmission Lines
☐ 39-155	Hoard*	Transit-System Modernization, Choice of Vehicle
☐ 39-156	Bryant & Newman	Electronic Measurement of Surge-Crest Voltages
☐ 39-157	Bryant & Newman	Measurement of Very Short Time Lags
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☐ 39-159	Holbrook & Dixon*	Load-Rating Theory for Multichannel Amplifiers
☐ 39-160	Kurtz	Dynamic Characteristics, Single-Phase Induction Motor
☐ 39-161	Parsons	Vaults for A-C Secondary Networks
☐ 39-162	Stephens & Gehrenbeck*	Corrosion of Fine Copper Wires Carrying a Potential
☐ 39-163	Willey	Emergency Radio as Safeguard to Telephone Service

Scranton Meeting

☐ 39-164	Renshaw*	Mercury-Arc Rectifiers in Coal Mining
☐ 39-165	Bell	Lightning Investigation on a 220-Kv System, III
☐ 39-166	Caldwell	Electrical Apparatus in the Steel Industry
☐ 39-167	Armstrong*	NEMA Resistors for Motor Starting and Speed Control
☐ 39-168	Penney*	Temperature Rise of Electrical Apparatus
☐ 39-169	Compton	Class B Insulation for Auxiliary-Type D-C Motors
☐ 39-170	Edmunds	Adjustable-Speed A-C Motors
☐ 39-171	Beavers	Selection of Distribution-Transformer Size
☐ 39-172	Hentz & Thielman	Power Supply for Suburban Areas

Winter Convention

☐ 40-4	Torchio	Railway Power Supply
☐ 40-5	Bellaschi & Palermo	Analysis of Transient Voltages in Networks
☐ 40-6	AIEE Committee Report	Report on Power Generation
☐ 40-7	Alexanderson, Edwards & Bowman	Dynamoelectric Amplifier for Power Control
☐ 40-8	Foust & Scott*	Breakdown Tests on Oil-Treated Paper-Insulated Cable
☐ 40-10	Fisher	The Design Characteristics of Amplidyne Generators
☐ 40-12	Morgan, Brown & Schumer	Induction Motor Characteristics at High Slip
☐ 40-13	Morrill	Harmonic Theory of Noise in Induction Motors
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☐ 40-27	Hill	Power Supply for Railroad Electrification
☐ 40-28	Craton & Turner	Electric Braking for Railroad and Urban Transit Equipment
☐ 40-29	Withington	Trends in Railroad Motive Power
☐ 40-34	Davis & Eddy*	Impulse Strength of Cable Insulation
☐ 40-36	Sporn & Gross	Rationalization of System Insulation—III
☐ 40-37	AIEE Committee Report	Proposed Standards for Outdoor Bushings
☐ 40-38	AIEE & EEI-NEMA Joint Report	Recommendations for High-Voltage Testing
☐ 40-39	Clark	The "Speedomax" Power-Level Recorder
☐ 40-40	Faucett, Keener & Helm	The Accuracy of Watt-Hour Meters on Intermittent Loads
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☐ 40-61	Berkey	Enclosed Spark Gaps
☐ 40-68	Camilli & Ten Broeck	Method for Determination of Current-Transformer Errors
☐ 40-69	Gebelein & Elsi	Analysis of Bushing Current-Transformer Performance
☐ 40-70	Sinks	Transient Characteristics of Current Transformers
☐ 40-72	Slepian & Brubaker*	Condensation of Mercury in Mercury-Arc Tubes
☐ 40-73	Pakala & Batten*	Arc-Backs in High-Current Mercury-Arc Rectifiers
☐ 40-75	Stevenson & Ramo*	New Postgraduate Course in High-Frequency Engineering
☐ 40-76	Sporn & Porter	Operating Experience With Hydrogen-Cooled Condenser
☐ 40-77	Clark	Water Solution in High-Voltage Dielectric Liquids
☐ 40-78	Whitney & Criner	Short-Circuit Torques in Turbine Generators
☐ 40-79	Fechheimer	Heating of a D-C Armature
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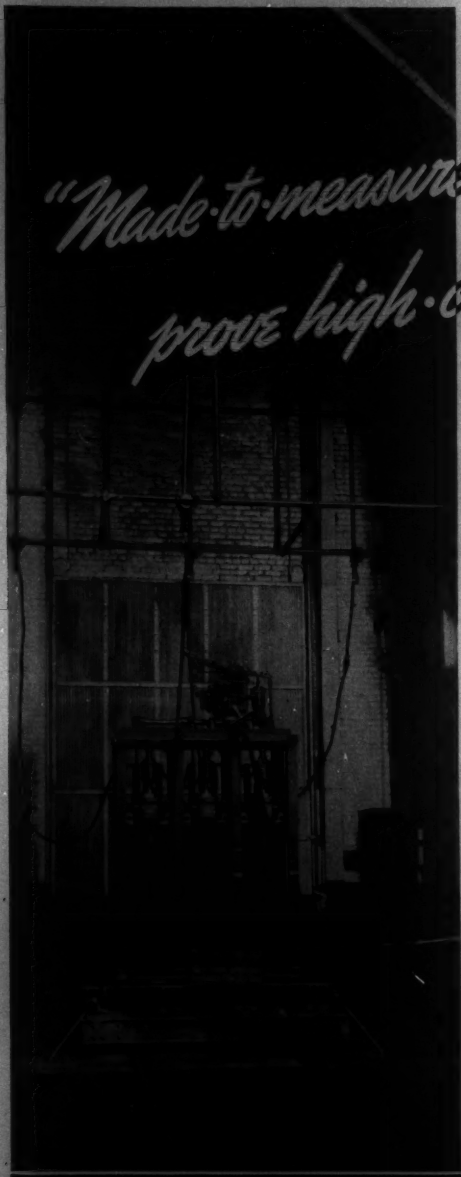

"Made-to-measure" Short Circuits prove high-capacity breakers

High power laboratory duplicates actual conditions to test highest capacity breakers at full rating

How circuit breakers will act under any condition of actual service no longer involves the slightest element of uncertainty. The unique facilities of the Westinghouse High Power Laboratory have eliminated all guesswork—performance of even the highest voltage air circuit breaker now is proved to the limit by simultaneous voltage and current surges duplicating actual service conditions.

These "made-to-measure" short circuits have enabled Westinghouse engineers to perfect new, more compact and higher capacity air breakers . . . with ratings as high as 1,500,000 kv-a at 15 kv.

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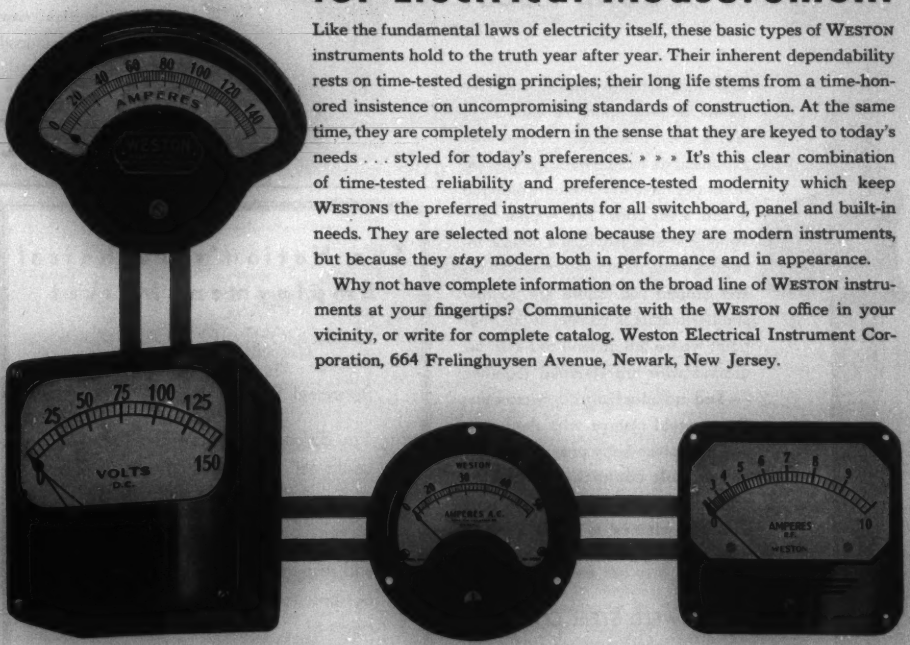
for Electrical Measurement



Like the fundamental laws of electricity itself, these basic types of WESTON instruments hold to the truth year after year. Their inherent dependability rests on time-tested design principles; their long life stems from a time-honored insistence on uncompromising standards of construction. At the same time, they are completely modern in the sense that they are keyed to today's needs . . . styled for today's preferences. » » » It's this clear combination of time-tested reliability and preference-tested modernity which keep WESTONS the preferred instruments for all switchboard, panel and built-in needs. They are selected not alone because they are modern instruments, but because they *stay* modern both in performance and in appearance.

Why not have complete information on the broad line of WESTON instruments at your fingertips? Communicate with the WESTON office in your vicinity, or write for complete catalog. Weston Electrical Instrument Corporation, 664 Frelinghuysen Avenue, Newark, New Jersey.

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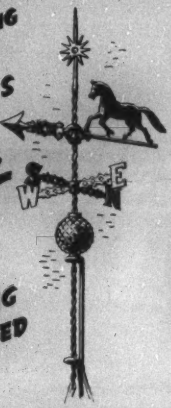
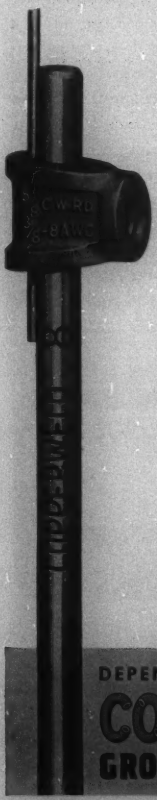


THIS FUNDAMENTAL FOR GOOD GROUNDING REMAINS UNCHANGED

—"CONNECT TO DEPENDABLE GROUND RODS"



Lightning arrester performance depends largely upon the ground to which it is connected. Copperweld ground rods have a thick copper exterior permanently molten-welded to a stiff steel core. The copper prevents rust and provides a copper-to-copper contact between ground wire and ground rod. There are no dissimilar metals in contact at the vital point where the ground rod and the ground wire are clamped together — and no electrolytic corrosion. Copperweld clamps with their rugged, one-piece body provide simple, dependable connections. Specify non-rusting Copperweld ground rods and clamps to make sure of *dependable* grounds.

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GROUND RODS and CLAMPS

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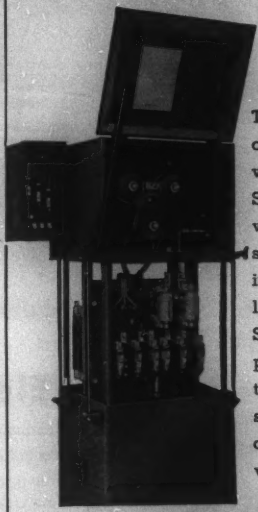

The Rowan combination oil immersed reduced voltage Impedance Starter is now available with Air-Seal fuses and safety disconnect switch incorporated and interlocked in one unit. Sealed-off terminal compartment and straight-thru conduit outlets are standard in this new combination reduced voltage starter.

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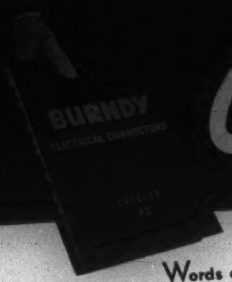

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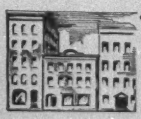

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Employment Bulletin

Engineering Societies Personnel Service, Inc.

MAINTAINED for their members by the national societies of civil, mining, mechanical, and electrical engineers, in co-operation with other organizations. An inquiry to any of the three offices will bring full information.

A weekly bulletin of engineering positions open is available to members of the co-operating societies at a subscription of $3 per quarter or $10 per annum, payable in advance.

In the interest of effective service, it is essential that members using the employment service keep the bureau office serving them advised at reasonable intervals concerning their availability for employment, concerning any change in status, and immediately upon acceptance of any employment.

Employers interested in the following announcements should address replies to the key numbers indicated, and mail to the New York office.

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ELECTRICAL DESIGNERS who have had a minimum of three to five years' experience in the design and layout of power and lighting systems for all types of buildings and the design and layout of power plants, substations and transmission systems. Experience limited to the design of electrical appliances, small machinery, radios, sound transmission or research work will not be acceptable. Location, Central America. Y-5398.

ELECTRICAL ENGINEER experienced in transformer or machine design and related problems. Location, Pennsylvania. Y-5975.

Men Available

E.E. GRAD, 1926; 36, single; 19 mos General Elec Test Course; 10 yrs steam and diesel power plant oprn, indus maintenance, motor rewind, constr, some pub util exper. Speak Spanish. E-664.

ELEC ENGR, Fellow AIEE; exper in management of ceramic and light mfg; des and constr of high voltage stations and special purpose machines and processes; successful as sales engr. E-665.

B.S., M.S., 1934, M.I.T.; 32, married; 5 yrs exper originating, developing and mfg appliances, instruments, power apparatus. Desires pos with future in this line or allied field. Available immed. E-666.

REC GRAD; 23, single, good health. Studied transm line calculations, des transf and motors, transients, electronics and antenna designs. Desires pos in one of above. Location immaterial. E-667.

B.S.E.E., 1930, Oregon State Col. 2 yrs test engr com lab; 6 yrs foreman, E E for chem mfg plant. Employed. Desires engg pos with util or elec mfg co with future. Available immed. E-668-404-C-8-San Francisco.

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B.S.E.E., 1938, U. of Wisconsin; 24, married; 2 yrs exper machine changeovers, spot, projection, butt welding; electronic, air control, elec maint. Desires pos mfg industry with engg future. Now employed. E-670-357-Chicago.

B.S.E.E., 1939, So. Dakota State School of Mines; 26, single; exper in treatment of boiler feed water. Desires pos with util co or consulting engr. E-671-163-Chicago.

JR ELEC ENGR, B.S.E.E., U.S.C., 1937; 26, married; 3½ yrs oil refinery exper; elec draftg, des; pwr factor studies; instal, maintenance, repair elec apparatus, transm lines. Desires pos pwr generation, transm. Available immed; location immaterial. E-672-403-C-3-San Francisco.

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B.S., M.S., Case, 1936; 23, single; 2 yrs universal motors and appliances; desires pos in elec specialties, it eqpt or col teaching. Interested in product des, devpmt, circuit theory. E-674.

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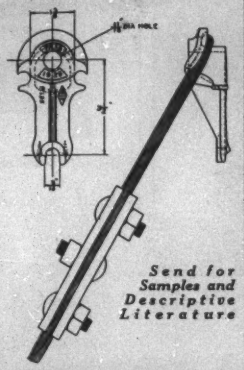

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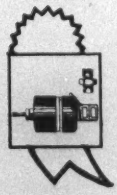

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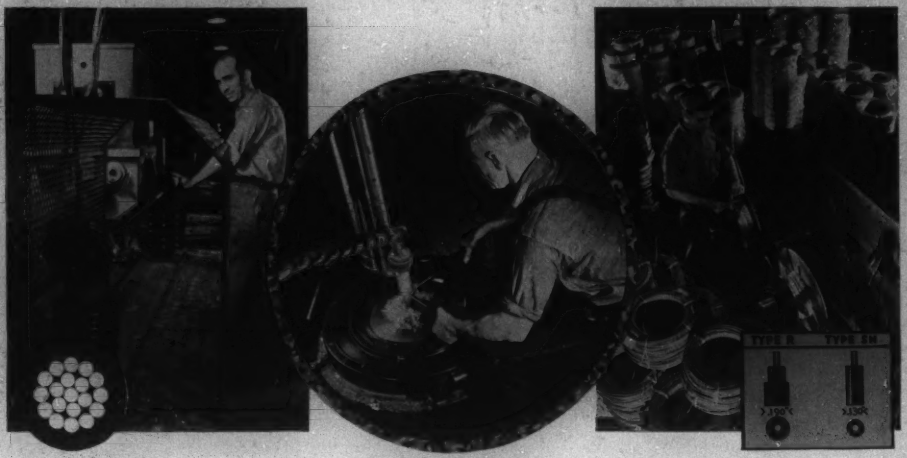

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